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Visual Interactive Knowledge Management for Multicriteria Decision Making and Ranking in Linked Open Data Environments

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A la mémoire de mon père et mes grands-parents,

à ma famille.

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Droits d’auteurs

«VISUELLE INTERACTIVE GESTION DES CONNAISSANCES POUR LA PRISE DE DÉCISIONS ET LE CLASSEMENT MULTICRITÈRES DANS DES ENVIRONNEMENTS DE DONNÉES OUVERTES LIÉS»

Résumé

Le doctorat impliqués la recherche dans le domaine des représentations visuelles assistées par des technologies sémantiques et des ontologies afin de soutenir les décisions et les procédures d'élaboration des politiques, dans le cadre de la recherche et des systèmes d'information académique. Les visualisations seront également prises en charge par l'exploration de données et les processus d'extraction de connaissances dans l'environnement de données liées. Pour élaborer, les techniques d'analyse visuelle seront utilisées pour l'organisation des visualisations afin de présenter l'information de manière à utiliser les capacités perceptuelles humaines et aideront éventuellement les procédures de prise de décision et de prise de décision. En outre, la représentation visuelle et, par conséquent, les processus décisionnels et décisionnels seront améliorés au moyen des technologies sémantiques basées sur des modèles conceptuels sous forme d'ontologies.

Ainsi, l'objectif principal de la thèse de doctorat proposée consiste en la combinaison des technologies sémantiques clés et des techniques de visualisation interactive basées principalement sur la perception du graphique afin de rendre les systèmes de prise de décision plus efficaces. Le domaine de la demande sera le système de recherche et d'information académique.

Domaine d'application: Recherche de gestion de l'information et d'exploration de données éducatives dans l'enseignement supérieur

Mots clés: Visualisation, Analyse visuelle, Technologies sémantiques, Extraction de connaissances, Ontologies, Données liées.

«VISUAL INTERACTIVE KNOWLEDGE MANAGEMENT FOR MULTICRITERIA DECISION MAKING AND RANKING IN LINKED OPEN DATA ENVIRONMENTS»

Abstract

The dissertation herein involves research in the field of the visual representations aided by semantic technologies and ontologies in order to support decisions and policy making procedures, in the framework of research and academic information systems. The visualizations will be also supported by data mining and knowledge extraction processes in the linked data environment. To elaborate, visual analytics' techniques will be employed for the organization of the visualizations in order to present the information in such a way that will utilize the human perceptual abilities and that will eventually assist the decision support and policy making procedures. Furthermore, the visual representation and consequently the decision and policy making processes will be ameliorated by the means of the semantic technologies based on conceptual models in the form of ontologies.

Thus, the main objective of the proposed doctoral thesis consists the combination of the key semantic technologies with interactive visualisations techniques based mainly on graph's perception in order to make decision support systems more effective. The application field will be the research and academic information systems.

Application field: Research information management and educational data mining in Higher Education

Key words: Visualization, Visual analytics, Semantic Technologies, Knowledge extraction, Ontologies, Linked Data.

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Chapter 1 . Introduction

1.1 Introduction

Ranking constitutes a way of solving numerous problems, ranging from defining the classification of candidates for a specific task to concluding to the most suitable action among a set of alternatives that may lead to the desired outcome. Rankings may depend either on a single, or numerous variables. Single dimension ranking problems are usually less complex, while in the case of multiple criteria the resolution of the problem becomes more perplexed and calls for a more elaborate solution. In order to respond to multidimensional ranking, all the facets that contribute to the formation of the final decision must be taken into account, along with the significance that each feature holds in the specified problem. An effective way to handle that kind of computer-aided decision making process is the Multiple Criteria Decision Making (MCDM).

Multiple-Criteria Decision Making involves the process of many variables to support the decision maker with a specific problem. However, there are several ways to enhance the MCDM process and to aid the decision maker both efficiently and effectively. The introduction of the Semantic Web technologies to the core of the MCDM procedure ameliorate the process by enabling the reproducibility and transparency of the method and its results, the interoperability of the data and the adaptability of the system to other application fields. Furthermore, by employing visual analytics in the presentation stage of the MCDM process, the information becomes easier processible and understandable by the decision maker, leading to more informed decisions made in less time and with less effort.

Especially, when MCDM is applied in the ranking problematic, the before mentioned enhancements are even more needed. The multiple-criteria ranking problematic implicates the classification of the alternatives based on multivariate data, while the multidimensionality of a domain indicates added levels of complexity. The involvement of the semantic web in the multidimensional data ranking expedite the whole lifecycle of the information, including the input, structure, management, export and reuse of information, while the visual analytics ease the presentation and the understanding of the complex and multidimensional information and results. This thesis is focused on multidimensional ranking facilitated by a MCDM method aided by visual analytics and semantic web technologies. A brief description of the involved disciplines follows in the next paragraphs.

1.1.1 MCDM

Multiple-criteria decision-making (MCDM) or multiple-criteria decision analysis (MCDA) refers to decision making that relies on the processing of multiple attributes. MCDM problems are encountered often in everyday life. Examples of MCDM problems range from selecting a Personal Computer to purchase based on its various characteristics, to choosing employees to recruit for a job based on specific criteria. Many different approaches have been developed to respond to multiple criteria decision making. These methods are applicable to several problems that can be classified to the following categories: choice, sorting, ranking and description [98]. Any MCDM problem comprises four components: the set of alternatives, the set of criteria, the outcome of every choice and the preference structures [99].

In MCDM, the decision makers set their preferences on the various criteria in order to retrieve a solution that matches their requirements. This process is considered subjective and ultimately depends on the opinion and the needs of the involved decision maker.

1.1.2 Visual analytics

Visual analytics concerns analytical reasoning facilitated by interactive human-machine interfaces [100]. It meant to solve problems of great size and high complexity by taking advantage and augmenting the human cognitive capabilities. The goal of visual analytics is to *"make the way of processing data and information transparent for analytical discourse"* [19] and to aid understanding, reasoning and decision making in such complex problems.

Visual representation enables the processing of larger amount of information than in text, due to the increased visual human perception [17]. They also empower deeper understanding of complex multi-dimensional data, revealing information that otherwise will not be obvious [17]. Thus, the information becomes easier detectable.

1.1.3 Ontologies and the Semantic Web

Nowadays, the Linked Open Data (LOD) cloud is growing at a fast pace. Datasets from multiple domains are published in Linked Open Data underlining both the significance of opening the data rather than keep it in data silos, as well as linking the data with other already existing datasets. Semantic web technologies provide the means and the techniques to generate LOD datasets.

Ontology is one of the components of the Semantic Web that is utilized to provide structure of the information in an explicit way. Furthermore, the semantic web introduces several valuable characteristics to datasets, such as transferability, open access and interoperability [133].

1.2 Structure

The remaining sections of this chapter are structured as follows: the motivation for the dissertation is described. Moreover, the thesis overview is presented along with the related efforts on the domain, followed by the hypothesis and the thesis objectives are outlined. The proposed approach and the research methodology are also described, then the contribution areas are referred and the prospective benefits from this research are analyzed. Finally, the thesis organization is outlined followed by the summary and conclusions of the introduction.

1.3 Motivation

The motivation for our work stems from the need of a reproducible and transparent multidimensional ranking method that is capable of using state of the art technology to adapt in various settings, as well as actively and proactively support the stakeholders during the decision making procedure. Due to the nature of this problem multiple scientific areas are involved:

i) the decision making and more specifically the MCDM,

ii) the visual analytics for the interactive support of the stakeholders, and

iii) the semantic web for the formation of the interoperable data.

1.4 Thesis overview

The thesis is concentrated on the visual enabled ontology-based multiple criteria decision support, focused on the ranking problematic. The Multidimensional Ontology-Based Visual Ranking is based on visual analytics, ontologies and Semantic Web technologies to enhance, boost and generalize the decision making process. Apart from combining the before mentioned disciplines, we propose a novel technique for multifaceted ranking that seamlessly integrates MCDM, visual analytics and Semantic Web (Figure 1).

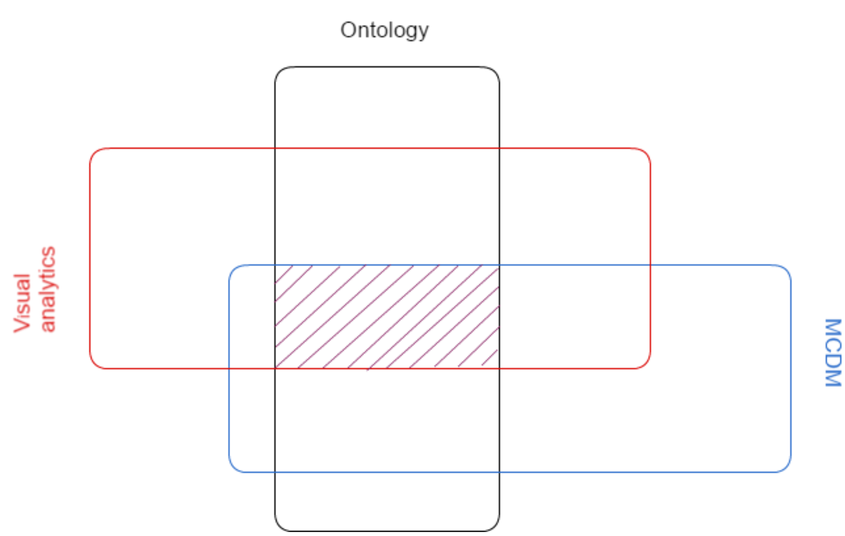


Figure 1 – The main topics of research

1.4.1 Related efforts

Though there are several methods that successfully rank the alternatives based on multiple criteria, little work has been done in multifaceted ranking [130, 131]. Bearing in mind that all the efforts for multifaceted ranking correspond to multiple levels of hierarchy [130, 131], there is none approach that clusters the criteria into groups based on their similarity. In an approach that adopts multiple levels of hierarchy in MCDM, a problem is divided into sub-problems that facilitate the specification of a preference model at each node of the hierarchy [130], while another method decomposes a problem into individual sub-problems in different levels of hierarchy [131]. However, treating the criteria in groups with related subjects, allows the generation of individual and combinable ranking sub-profiles that are able to shed light to all the separate missions of an entity.

Although, there are approaches that combine the MCDM approaches with ontologies [109, 110, 111, 112, 113], several methods utilize the ontologies as a structure mechanism that is not implicated to the decision making [114, 115, 116] or the multiple criteria decision mechanism [117, 118, 119, 120], while other methods solely rely on the ontology to provide the decision making process by the means of the ontology reasoning [109, 121 - 129]. Nevertheless, there are added benefits from employing a hybrid approach that merges a MCDM method with ontologies and exploits them at all the stages of the decision making process. The facilitation of the structure of the MCDM method information by ontologies diminishes the dependency of the data from the involved information system and vice versa. A methodology that implements a concrete decision making method allows for efficient and effective results on the multidimensional setting, while a reasoning mechanism based on ontologies provides deeper exploration and understanding of the information.

MCDM results are better perceived in visual form due to their size and complexity. As a result, visual representation has been used widely in MCDM [108]. Since visual analytics simplify the complex information by making it easier processible. There are only a few efforts that implement visual analytics in MCDM [101 - 107]. Visual analytics have been used in MCDM for textile composite materials selection [101], for finding the ideal landfill monitoring process [102], for observing and comprehending critical infrastructures, cascading infrastructure effects, and managing crisis response [105], or the evaluation of building design alternatives [103]. It has been also utilized for evaluating low energy building design alternatives [104] and for geo-social visual analytics [106]. The introduction of the interactive multi-objective optimization (IMO), a new subdomain which merges visual analytics (VA) and Multiple Criteria Decision Making (MCDM) further proves the significance of the combination of those two fields [107].

Nonetheless, none of the before mentioned approaches is occupied with the multidimensional ranking of entities' performance. The proposed approach eases the decision making by presenting the multidimensional ranking in formation with the assistance of visual analytics.

1.5 Research problem and hypotheses/research questions

The research problem is related to the ranking of a domain, characterized by multiple dimensions and multiple criteria. The situation of relying on multifaceted data to rank a group of entities that belong to the same category generates an abundance of information that the human brain and perceptional abilities cannot process easily if it is not presented appropriately. It is quite difficult to manage the performance related data of numerous alternatives on multiple dimensions and criteria, and to conclude on which of the presented alternatives is more consistent with the stated requirements. While this problem has been addressed in textual form, there is also the need to visualize the results in an interactive manner. This problem impacts the user of the DSS in terms of time, effort and efficiency, because the process of filtering the information to meet the indicated specifications can be tedious, time consuming and error-prone.

It is of vital importance to be able to reproduce the results in order to check the validity of the rankings. In order for the rankings to be reproducible, the data upon which they are based should be available in an open and processible form. Nonetheless, the most rankings provide only their results and abstain from revealing the relevant data or process. Even for those rankings that provide their input data, it is challenging to reproduce them, due to the format of the data, which hinder the validation of the rankings. In the proposed approach, the entire ranking information, including inputs and outputs of the method, together with information about the process itself (because it is depicted in the ontology), can be exported in semantic web compliant format. Hence, the examination of ranking results from a third party becomes feasible and requires minimum effort. Furthermore, important information for the ranking domain can be overlooked due to the profusion of data. The decision maker should be able to access not only the outputs of the rankings, but also the information about the domain and the alternatives, so as to make an informed decision. To enable the deeper exploration of the information, the dataset is queried based on semantic web technologies.

The main objective of this work is to combine the power of visual analytics and Linked Open Data in order to assist the decision making process of the stakeholders in the context of multidimensional domains. The aim is to propose a methodology, in which each of these areas contributes its outmost to ameliorate the MCDM process. More detailed description is available at Chapter 3. Methodology.

This work contributes to the body of knowledge, by answering the following question:

1. How can a visual-aided ontology-based MCDM system facilitate informed and insightful decisions on multidimensional data?

This question can be further analyzed to the following sub-questions:

1.1. How can visual analytics be implemented and integrated in a MCDM system to aid the DM process?
1.2. How can ontologies be utilized to facilitate a MCDM ranking method regardless the domain?
1.3. How can visual analytics and semantic web technologies be combined in order to enhance the user-system interaction?
1.4. How can we make ranking deductions for multifaceted data irrespective of the context?

Moreover, our research responds to the following questions:

2. What is the current stage of ontology-based decision making methods and what are the research gaps?
3. Which are the prerequisites for an application domain in order to apply to it the Multidimensional Ontology-Based Visual Ranking framework?
4. What is the current stage on multidimensional MCDM approaches?

Our research focuses not only on bridging the gap and conglomerating these heterogeneous scientific domains, but proposes a concrete and reproducible methodology on ranking that will significantly assist the involved stakeholders, augment the efficacy of the decision making process and reduce the time spent on this task. In the following paragraphs, the research questions and their background in the literature will be outlined and also the related research gaps addressed by this study will be discussed.

- *RQ1: How can a visual-aided ontology-based MCDM system facilitate informed and insightful decisions on multidimensional data?*

MCDM methods involve the processing of multivariate data. Thus, the data required by a MCDM method, the process of the data and the presentation of the information implicate increased complexity and great volume. Visual analytics are used for reducing the intricacy of the information and for allowing the process of larger amount of data [17]. Likewise, semantic web technologies enable the discovery of information and relations within the data that would be inaccessible in any other way. The ontologies abstract the domain specific information from an information system making it receptive to other domains and adjustable to changes.

When it comes to information systems dedicated to decision making, it is essential to be able to effortlessly transfer the associated methodology to other application fields. The goal in this case is to construct a backbone for the visual aided decision making process facilitated by ontologies to host and contain the domain specific information through its whole lifecycle in the system. This methodology will be discussed further in section *4.6.1 Multidimensional Ontology Based Visual Ranking (MOBVR)*.

- *RQ1.1: How can visual analytics be implemented and integrated in a MCDM system to aid the DM process?*

Visual analytics accelerate the processing speed of the information [96]. To be more specific, the information when presented in visual form can be handled by humans more easily, due to the increased visual perception capabilities in relation to the processing of information in other form [97]. Especially, in MCDM, where the volume and the multiplicity of the information are great, it is essential to reduce the cognitive burden. However, the utilization of visual analytics in multidimensional decision making in ranking problematic is yet to be explored. This leads us to the RQ1.1.

Multidimensional ranking involves the processing and the weighting of the alternatives and results in the presentation of the ranking outputs. Since the ranking outputs are also multifaceted themselves, it is important to allow the user to conceive the presented information and to make their decision based on it. To amplify the perception abilities of the decision makers, we employ visualizations of the MCDM results with the multidimensional comparative ranking visualization. Capturing and displaying multidimensional information concerning the performance indicators of an entity also implicates complex and abstruse data that needs to be understood by the involved stakeholders. The aim is to design and implement a method, called fingerprint, which visually presents the multidimensional performance data of any entity, compared to other entities or based to predefined profiles. These features will be presented in *Chapter 4 – Methodology*.

- *RQ1.2: How can ontologies be utilized to facilitate a MCDM ranking method regardless the domain that would also enable deeper exploration of the data?*

Ontologies introduce several characteristics when they are used, such as interoperability and dynamic features [133]. They also allow profounder understanding of the data involved, because of the semantic relationships that are inherent in this type of information [134]. MCDM ranking can benefit from the semantic web technologies for a more independent and detailed investigation of the information. The multiple criteria decision making methodology can also be ameliorated by the transferability which is offered by the ontologies. Hence, it is vital to explore the merging of ontologies and MCDM in such a way that may benefit the decision maker. This matter will be described in section *Chapter 3. Methodology*.

- *RQ1.3: How can visual analytics and semantic web technologies be combined in order to enhance the user-system interaction?*

Visual analytics allow the user to process larger amount of information [135] and to more effortlessly comprehend the presented data [136]. So, they can be utilized to present ontology structured data and take advantage of the rich semantic information and relationships [137] to enable the user to access and process the relevant data. Nowadays, little work has been done in representing ontologies by visual analytics [138]. This feature will be discussed in *Chapter 4 – Methodology*.

- *RQ1.4: How can we make ranking deductions for multifaceted data irrespective of the context?*

Ranking multifaceted information involves the processing of large amount of complex data. The development of a multidimensional ranking approach that makes this process dynamic, generally applicable and permits its utilization in numerous application fields is facilitated by the semantic web. This aspect of the method will be presented in *Chapter 4 – Methodology*.

- *RQ2: Which are the prerequisites for an application domain in order to apply to it the Multidimensional Ontology-Based Visual Ranking framework?*

The proposed framework, the Multidimensional Ontology-Based Visual Ranking framework, is developed to respond to a certain type of problematic. More precisely, it aims to rank multidimensional disciplines based on a MCDM method. The requirements that an application domain must suffice in order for the MOBVR technique to be applied to it are described thoroughly in the MCDM competency check. The MCDM competency check constitutes a mandatory step prior to the application of the developed framework to a discipline that ensures their compatibility. The prerequisites in order for the MOBVR framework to be applied to a domain are described in section *4.3.4.1 The MOBVR competency check*.

- *RQ3: What is the current stage of decision making methods assisted by visual analytics and/or semantic web technologies and what are the research gaps?*

Ontologies have been utilized in decision making to ameliorate the process, to provide structure to the data and to promote sharing [132], or as a reasoning mechanism that entails decision support capabilities [109]. The majority of such ontology-based approaches employ decision making process, whereas fewer ontology-based approaches are utilized in MCDM systems. Several approaches that combine decision making or multiple criteria decision making and ontologies use the ontology as the source of the information needed from the decision making system, while others employ ontology reasoning mechanisms to facilitate the decision making process. Although ontologies have been utilized in decision making, there are just a few ontology-based MCDM methods and the majority of them are not dynamic since they are implemented to meet the specific needs of a single domain.

In the section *2.6.1 Literature review on the combination of decision making methods and ontologies* the current stage and the research gaps of ontology-based decision methods will be discussed. Visual analytics can enhance the knowledge and the decisions [150]. Therefore, the field of visual analytics for decision making [234] is constantly evolving. Although many decision making methods has been assisted by visual analytics, there are fewer multiple criteria decision making methods that utilize visual analytics. In the section *2.6.2 Literature review on the combination of decision making methods and visual analytics* will described the current stage of the decision making methods that are enhanced by visual analytics, as well as the identified research gaps.

Ontologies and visual analytics assist the deeper understanding and exploration of data and can foster the decision making process. There are a few methods that involve decision making, visual analytics and ontologies. Nonetheless, there are not any MCDM methods that employ visual analytics and ontologies to support decisions. The current stage of decision making methods facilitated by visual analytics and ontologies and the research gaps will be outlined in the section *2.6 Combining DM, visual analytics and ontologies*.

- *RQ4: What is the current stage on multidimensional MCDM approaches and what are the research gaps?*

MCDM approaches involve the processing of multiple variables. Usually, several of these variables have certain similarities among them. These variables can form separate profiles, which may judge the outcome of the decision making. Hence, it is important to be able to capture and express these profiles. However, the existing multifaceted MCDM methods consider multiple levels of criteria [130, 131], rather than clustering of the criteria that we consider in our method. The literature review will be discussed in the section *2.8.1.3 Literature review on multi-faceted MCDM ranking methods*.

The research questions are also addressed in the conducted research publications as shown in Figure 2. The research publications that were published concerning this thesis are the following:

1. Triperina, E., Sgouropoulou, C., Xydas, I., Terraz, O., & Miaoulis, G. (2015). Creating the context for exploiting linked open data in multidimensional academic ranking. *International Journal of Recent Contributions from Engineering, Science & IT (iJES), 3(3), 33-43*.
2. Triperina, E., Sgouropoulou, C., Xydas, I., Terraz, O., & Miaoulis, G. (2017, April). Assessing the performance of educational institutions: A multidimensional approach. In *Global Engineering Education Conference (EDUCON), 2017 IEEE* (pp. 1337-1344). IEEE.
3. Triperina, E., Bardis, G., Sgouropoulou, C., Xydas, I., Terraz, O., & Miaoulis, G. (2018). Visual-aided Ontology-Based Ranking on Multidimensional Data: A Case Study in Academia. *Data Technologies and Applications, Vol. 52 Issue: 3, pp.366-383, https://doi.org/10.1108/DTA-03-2017-0014*.

Publication 1: "Creating the Context for Exploiting Linked Open Data in Multidimensional Academic Ranking"

Research Questions that Publication 1 responds to:

- *RQ1: How can a visual-aided ontology-based MCDM system facilitate informed and insightful decisions on multidimensional data?*
- *RQ1.2: How can ontologies be utilized to facilitate a MCDM ranking method regardless the domain that would also enable deeper exploration of the data?*
- *RQ1.3: How can visual analytics and semantic web technologies be combined in order to enhance the user-system interaction?*
- *RQ1.4: How can we make ranking deductions for multifaceted data irrespective of the context?*

Publication 2: "Assessing Educational Instutions Performance: A Multidimensional Approach"

Research Questions that Publication 2 responds to:

- RQ1: How can a visual-aided ontology-based MCDM system facilitate informed and insightful decisions on multidimensional data?
- RQ1.1: How can visual analytics be implemented and integrated in a MCDM system to aid the DM process?
- RQ1.2: How can ontologies be utilized to facilitate a MCDM ranking method regardless the domain that would also enable deeper exploration of the data?
- RQ1.3: How can visual analytics and semantic web technologies be combined in order to enhance the user-system interaction?
- RQ1.4: How can we make ranking deductions for multifaceted data irrespective of the context?
- RQ2: Which are the prerequisites for an application domain in order to apply to it the Multidimensional Ontology-Based Visual Ranking framework?
- RQ4: What is the current stage on multidimensional MCDM approaches and what are the research gaps?

Publication 3: "Visual aided ontology-based ranking on multidimensional data: A case study on academia"

Research Questions that Publication 3 responds to:

- *RQ1: How can a visual-aided ontology-based MCDM system facilitate informed and insightful decisions on multidimensional data?*
- *RQ1.1: How can visual analytics be implemented and integrated in a MCDM system to aid the DM process?*
- *RQ1.3: How can visual analytics and semantic web technologies be combined in order to enhance the user-system interaction?*
- *RQ1.4: How can we make ranking deductions for multifaceted data irrespective of the context?*
- *RQ3: What is the current stage of decision making methods assisted by visual analytics and/or semantic web technologies and what are the research gaps?*
- *RQ4: What is the current stage on multidimensional MCDM approaches and what are the research gaps?*

Figure 2 – Publication and the addressed research questions

1.6 The proposed approach and research methodology

Multidimensional ranking involves the ranking of multiple criteria. The multiple criteria are grouped in several dimensions, which have similar characteristics. A multidimensional ranking system should satisfy the following needs:

- Access information related to the activities, the relationships and the interactions that happen within a unit.
- Gain insights about the performance of units, to compare them, or to learn about the ranking information of the units.
- Acquire information about the quality of the offered services or products of a unit.
- Simplify the complex multidimensional ranking information to aid the decision making process of the user.
- Enable the testing of the ranking information.

We have built a framework according to the before mentioned needs. The framework is composed by the data layer, the ontology layer, the dynamic multiple criteria decision making layer and the presentation layer. In the data layer the data aggregation takes place, where the information is accumulated from various sources. The data is unified and structured by the ontology in the ontology layer. The MOBVR (Multidimensional Ontology-Based Visual Ranking) ontology constitutes the core of the dynamic multiple criteria decision making layer, which assists the alignment between the ontology structured data to the information required for the ranking. The presentation layer consists of the ranking results facilitated by visual analytics and semantic web that aids the deeper understanding of the ranking information and the reusability layer allows the transferability of the data to other systems.

To validate the before described framework, two application domains have been selected that satisfy its prerequisites – the MOBVR competency check. The first domain is the academic discipline, whereas the second domain is the world development indicators derived by the World Bank. The before mentioned domains have been selected to satisfy the prerequisites of the MOBVR methodology. The proposed methodology includes the definition and implementation of an ontology for each involved application field. The first ontology is named AcademIS (AcademIS), and depicts research and education in the Higher Education Institutions (HEIs). The second ontology is the WDI-IS and captures the world development indicators. The domain ontologies (AcademIS and WDI-IS) function as a basis for the transformation of the information to Linked Open Data. In this document, we will call this process LODification. Following is the implementation of an information system, which (i) displays the contents of the dataset, (ii) provides interactive visualization of the data, (iii) applies a multidimensional ranking technique and (iv) visualizes its results, (v) computes the academic fingerprint of the institution and (vi) assists the user into shaping its own decisions.

In order to ensure the validity of our process, we have applied the methodology in two application fields. The required modification that should be applied to the method to host another application field will be also described. To further assure the validity of the proposed technique, we aim to evaluate the performance of Multidimensional Ontology Based Visual Ranking (MOBVR) prototype. After the design of the Multidimensional Ontology Based Visual Ranking (MOBVR) framework and the implementation of the respective prototype system, an evaluation of the aforementioned system will be conducted that will be presented in *Chapter 3 – Methodology*.

1.7 Contribution areas

In this paragraph, we will introduce the contribution areas of the thesis. The proposed thesis is multidisciplinary. Although our research is focused on the generation and implementation of a multiple criteria ranking approach, auxiliary methods have been developed to support the overall process. In the following section the major contributions of this approach will be described. More specifically, we propose:

<u>*In terms of methodology*</u>

- A hierarchical framework that ranks entities assisted by ontologies and visual MCDM, namely the **Multidimensional Ontology Based Visual Ranking (MOBVR)**.
- A **ranking theoretical methodology** with multiple criteria support.

- A new **visual enhanced ranking method** based on MDCM algorithms to aid the decision maker.
- A new technique on utilizing and unifying structured and unstructured data from heterogeneous sources based on ontologies, namely the **LODification method**.

Application related

- An interactive **semantic web interface** that allows both textual and **visual** representation of the information.

Focused on the application field

- A new ontology, the **AcademIS ontology**, which combines renowned narrow-scoped ontologies and extends them in terms of concepts and relationships and introduces rules.
- A new ontology, the **WDI (World Development Indicators) ontology**.
- An analysis of the **requirements** and **criteria** for the application of the process in the **academic field**.
- An analysis of the **requirements** and **criteria** for the application of the process in the **world development domain**.

First and foremost, through this approach a novel ontology is introduced that incorporates the characteristics of all the facets of academia, as well as their intersections. Moreover a domain model for the world development field. Another area, in which this doctoral thesis contributes, is the use of visualizations for the Linked Open Data. Graphs are the most common use of visualization for the Linked Open Data that solely reveal the structure of data, whereas in this effort, we showed the multidimensional relationships of the data. The visualization aided multiple criteria decision making methodology is also proposed in the dissertation. Another contribution of this dissertation is the introduction of the academic unit fingerprint, which measures the proportion of an institution based on specific profiles. For instance, when the selected profile is the education, the system inspects only the characteristics that are relevant to education and defines the score of the institution based only on these characteristics.

1.7.1 Multidimensional Ontology Based Visual Ranking (MOBVR)

The motivation of this work was to exploit the advantages of MCDM in the ranking problematic and to ameliorate them with the introduction of visual analytics and ontologies. To elaborate, this approach is focused on:

- Building a framework for an automated multidimensional ranking approach of a specific knowledge domain, structuring the data based on an ontology and assisting the decision making process with visual analytics. The specific domains that this approach was concentrated were the academia and the world development indicators.
- The introduction of domain specific information to a semantic web information system.
- A specific data flow, which the information should follow in order to be input in the system, formatted in a specific manner with the use of ontologies, processed by the MCDM algorithm, presented in the interface and in the visual analytics and finally be output from the information system.

1.8 Prospective Benefits

The benefit that may derive from this thesis is the exploration of the intersection of Decision Support, Visual Analytics and Semantic Web, which has not been considered yet. Apart from the conjunction of the various fields into a single one, other advantages may arise from this attempt, such as an enhanced solution for the multidimensional ranking, in terms of time, effort and user experience.

1.9 Thesis organization

The thesis is organized as follows: First, we review the state of the art of the relevant areas in **Chapter 2**, including the visual analytics, the decision making systems and more specifically the MCDM systems and the Semantic Web.

We describe the methodology of our approach in the **3rd Chapter**, by presenting the related stages of the methodology and providing case studies, in which the proposed methodology can be utilized.

In **Chapter 4**, which corresponds to the prototype system implementation, we define all the components of our prototype system and we showcase our two case studies. The first case study concerns the application field of research and education in Linked Open Data, while the other regards the world development indicators in Linked Open Data setting.

In **Chapter 5**, we discuss the conclusions and perspectives of our research regarding the contributions, the main findings, the interpretation of the research and the results, as well as the implications of our methodology. Additionally, the recommendations for future work are also presented.

Finally, **Appendix 1** provides the required background of academic ontologies.

1.10 Summary and conclusion

The Multidimensional Ontology Based Visual Ranking (MOBVR) framework aims to exploit the benefits that the research areas of visual analytics and ontologies introduce in the multiple criteria decision making. In the following chapters we will thoroughly describe the problem statement, the literature review, the methodology, the results and the consequences of our research.

Chapter 2 . Literature overview

2.1 Introduction

As mentioned before, this thesis is concentrated on multidimensional ranking based on a MCDM method that is assisted by visual analytics and semantic web technologies to support the decision-making process. The second chapter presents all the necessary background information of all the main thematic areas that the thesis deals with. More specifically, it provides a thorough description of the background information of decision making – especially when multiple criteria are involved, visual analytics and semantic web, as well as background information about their combination according to the literature.

2.2 Structure

The remaining sections of the second chapter are structured as follows: firstly the scientific area of decision making is presented, along with the definitions of the important terms of the area and the literature review of decision making, followed by the description of the multiple criteria decision making, the definitions of its important terms and its literature review. In the MCDM subsection, an overview of the outranking methods and with a focus on the methods of the ELECTRE family is presented. Subsequently, a thorough description of the ELECTRE III method, the specific terms used in this method and the algorithm of the ELECTRE III are available.

In section 2.4, the scientific area of visual analytics is described. In the aforementioned section, the history of the visual analytics is referred, followed by a comparison between visual analytics and visualizations. Then, the term of interactive visualizations is described and the visual analytics process is demonstrated, while the utilization of the visual analytics in the presentation of multidimensional dataset is explored. The human cognition and perception and its connection with visual analytics is also introduced.

Section 2.5 provides an analysis of the semantic web and its constituents. Terms such as ontologies, linked data and linked open data are described also in this section, followed by the presentation of the semantic organization of the data.

In the Section 2.6, the literature review of the combination of the involved scientific areas is introduced. First, the literature review of the combination of the decision-making methods and ontologies is presented, which is divided to combination of the ontologies with decision making methods or with multiple criteria decision making. In these cases, the ontologies can be used as a source of information, or they can facilitate the reasoning mechanisms. Then, a literature review of the multifaceted MCDM ranking methods is provided. The available approaches that involve MCDM methods on the field of academic ranking are then explored. Furthermore, the combination of decision making methods and visual analytics are then presented. Following, the literature review on the synergy of visual analytics and ontologies is explicated. Finally, the summary and conclusion of the literature review is outlined.

2.3 Decision support

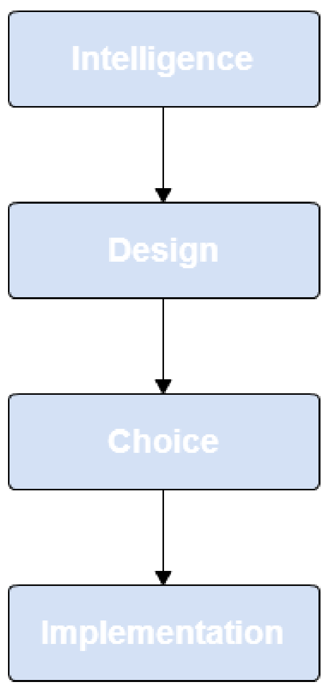


Figure 3 - Simon's phases of decision making [26]

Decision making refers to the identification and selection between alternatives according their values, as well as the decision maker's preferences. Decision making is the process that involves selection among two or more alternatives towards one or more goals [8, 24]. It is based on the scientific areas of Operations Research (OR) or Management Science (MS), which relied on mathematical modeling to provide solutions to real world problems by representing them with models [24], and Management Information Systems (MIS), which is focused on designing, implementing and providing computer-based systems to managers to accommodate administrative and management activities [180].

The phases of the decision-making process include: i) the intelligence phase, ii) the design phase, iii) the choice and iv) the implementation phases. The first phase denotes the identification, conceptualization and analysis of the problem, as well as the monitoring of the last phase, which is the implementation phase. The second phase, the design phase, involves the comprehension of the problem, the identification and analysis of the possible solutions and the examination of their viability. This phase also corresponds to the creation of a model of the system. In the third phase, a solution is examined, evaluated, suggested and selected for the constructed model, while in the last phase, the suggested solution is implemented.

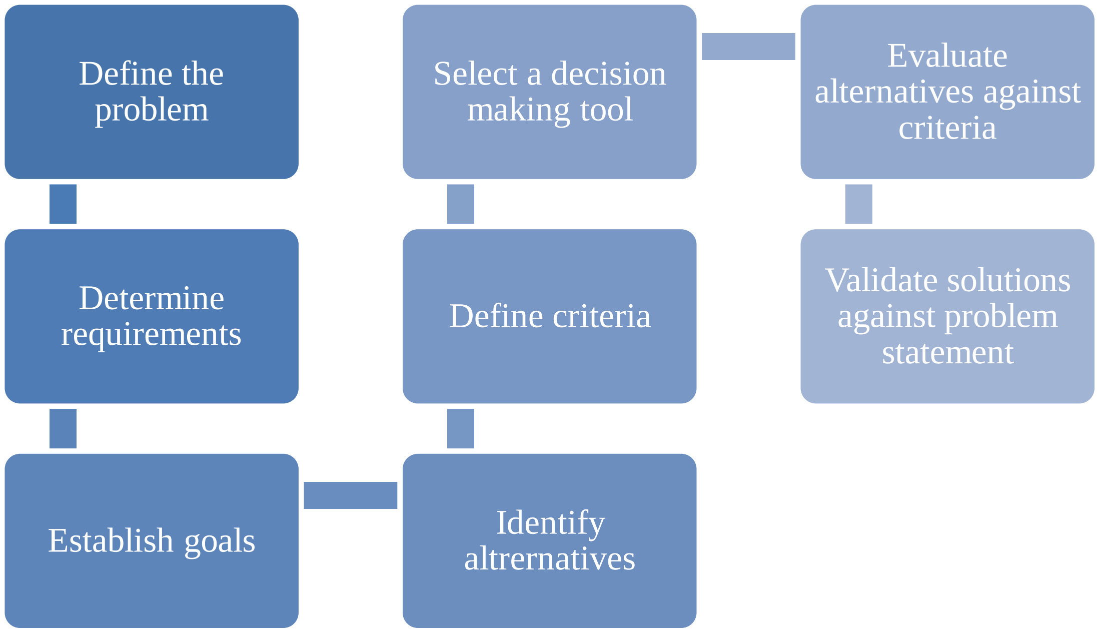


Figure 4 – Decision making process steps

According to Baker et al, 2001 [7], the steps of the decision-making process are:

1. The definition of the problem, which corresponds to the description of the problem in an unambiguous, short-length problem statement that takes into account both initial and anticipated conditions.
2. The determination of the requirements and goals. Requirements state the conditions that a solution must meet, while goals constitute general statements of anticipated and required values that should be indicated positively.
3. The establishment of the goals.
4. The identification of the alternatives. An alternative is a way to transform the initial state into the desired one.
5. The definition of the criteria, which are independent from each other and significant for the problem. They indicate the degree in which an alternative achieves the goals.
6. The identification of the decision-making tool based on the complexity of the problem.
7. The assessment of the alternatives against the criteria.
8. The final step of the process is the validation of solutions.

Decision support system (DSS) is a term, which describes information systems that facilitate decision-making activities and support a wide diversity of decision tasks. The history of the development of DSS commences in the mid-1960s [157]. Throughout the couple following decades, the DSS concept has evolved into a field of research [162]. DSS is defined as a computer-based information system, which involves models, analytical methods, as well as data and allows for contribution from the decision maker, to provide a solution to semi-structured and unstructured [161, 165, 166, 167, 169], or even to ill-structured problems [162]. The fundamental components of DSS architecture are: the database, knowledge base, the model and the user interface [170].

DSS can be classified in various ways. The most representative classification schemes will be presented subsequently. Holsapple and Whinston classifies DSS as follows: Text Oriented DSS, Database Oriented, Spreadsheet Oriented, Solver Oriented DSS, Rules Oriented and Compound DSS [173]. Alter classification of the DSSs has been conducted according to *"the degree of action implication of system outputs"* [171, 172], in the following categories: (i) file drawer systems, (ii) data analysis systems, (iii) analysis information systems, (iv) accounting models, (v) representational models, (vi) optimization models, and (vii) suggestion models. Donovan and Madnick classified DSSs as institutional, for recurring decisions, or ad hoc, for decisions that happen just once [174], whereas Hackathorn and Keen categorized DSSs in the subsequent groups: personal, group and organizational DSSs [175]. Finally, Power suggested the following broad categories: Data driven DSS, Model driven DSS, Knowledge driven DSS, Document driven DSS, Communication driven and group DSS [159].

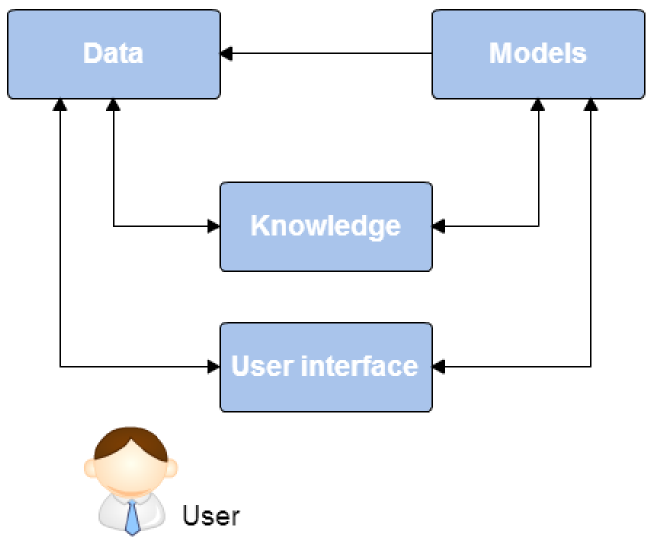


Figure 5 – High level architecture of a Decision Support system (DSS) [24]

2.3.1 Multiple criteria decision making

Multiple Criteria Decision Making (MCDM), Multiple Criteria Decision Analysis (MCDA) or Multi-criteria Analysis (MCA) involves the selection between countable or uncountable set of alternatives, based on two or more criteria. The criteria are the standards by which something can be decided, the alternatives constitute the possible solutions of the problem at hand, while the decision space corresponds to the range of the possible decisions that are available to the decision maker and is defined as the area, in which all the values of the variables are located, whereas the criterion outcome space is the domain formed by the related consequences of these variables [177].

The scientific area of MCDA/MCDM supports decisions in ill-structured problems with contradicting multiple criteria, goals, objectives and perspectives [176]. The systems that structure and solve these problems are called Multiple Criteria Decision Support Systems (MCDSS) [3]. In MCDM, there is not an optimal or unambiguous solution, since different aims generate different recommendations [176]. Based on the existence of trade-offs, MCDM methods can be distinguished in compensatory, which implies the existence of tradeoffs, or non-compensatory, in which there are no counterweights [179]. Multiple criteria decision-making can be also divided in two subcategories, the multiple attribute decision making (MADM) and the multiple criteria design multiple objective decision making (MODM). The former type consists of finite number of alternatives (discrete decision space), explicitly known when the solution process starts [6], while the latter comprises alternatives, which are not explicitly known (continuous decision space) and derive by mathematical models. The number of alternatives in MODM can be either infinite uncountable or extensive and countable [2]. A classification of the MADM methods can be according to the data they use. In this case, the methods can be deterministic, nondeterministic (stochastic), or fuzzy [178], whereas some problems call for combinations of the above data types (e.g. problems that involve stochastic and fuzzy data). MADM methods can be divided into single decision maker MADM and group decision making MADM methods, based on the amount of decision makers that take part in the decision-making process [178]. MCDA methods may belong in one of the following groups: value measurement models, goal, aspiration or reference level models and outranking models [181].

Roy [4] has described four possible problematics for discrete set of alternatives, described by several criteria: choice, sorting, ranking and description.

- Choice, where the goal is the selection of an alternative from a set of alternatives.

- Classification/sorting, in which the alternatives are organized in predefined and homogenous groups in a preference order.
- Ranking that provides the alternatives in an ascending or descending order.
- Description that explicates the alternatives regarding their distinguishing features.

Choice, classification/sorting and ranking problematic generate a specific evaluation result. Choice and ranking problematic are based on relative judgments in order to result to this outcome. Thus, the evaluation outcome depends on the considered set of alternatives. Classification/sorting problematic requires absolute judgments from the decision-maker.

Table 1 – A classification of MCDM methods

Multi-objective Optimization (MOO)	**Multi-Attribute Utility Theory**	**Analytic hierarchy**	**Outranking**	**Other methods**
Weighted Sum Method	Multi-attribute utility theory (MAUT)	Analytic hierarchy process (AHP)	ELECTRE	Fuzzy methods
ε-Constraint Method	Multi-attribute value theory (MAVT)		PROMETHEE	Rough set theory
Weighted Metric Method	UTA	Analytic network process (ANP)	ORESTE	Preference disaggregation
Strength Pareto EA (SPEA)	TOPSIS		ARGUS	
	SMART		IRIS	

2.3.1.1 Multi-objective Optimization (MOO)

Optimization is focused on the minimization or maximization of one or more objectives. The objectives are expressed as functions of variables. A single-objective optimization problem can be formulated as follows: min f(x), $x \in S$, where f is scalar function and S the set of constraints, for which $S = \{x \in \mathbb{R}^m : h(x) = 0, g(x) \geq 0\}$. Multi-objective optimization (MOO) [194], which is also referred as multi-criteria or multi-attribute optimization, aims to optimize two or more conflicting objectives at the same time, while taking into consideration a set of constraints. A multi-objective optimization problem can be formulated as follows: min $(f_1(x), f_2(x), \ldots, f_n(x))$, $x \in S$, where $n>1$ and S is the set of constraints, as defined above in the single-objective optimization. The objective vector belongs to the objective space, and the feasible set under F is called the attained set and is indicated with $C=\{y \in \mathbb{R}^n : y = f(x), x \in S\}$. A vector $x^* \in S$ is the Pareto optimal for a multi-objective problem, if all other vectors $x \in S$ have a higher value for at least one of the objective functions f_i, with $i = 1,...,n$, or have the same value for all the objective functions.

Multi-objective classification techniques can be classified to the following categories: a priori preference articulation, a posteriori preference articulation and progressive preference articulation [196]. The first category involves decisions before searching and comprises the methods in which the decision maker can conclude to a pre-ordering of the objectives or to an achievable goal before the search. In the second category, search takes place prior to decision making, so the involved methods do not require prior preference information from the decision maker. The third category integrates search and decision making and they are composed of three phases, i) the search of a non-dominated solution, ii) the feedback of the decision maker about the non-dominated solution, as well as the appropriate modifications to the preferences of the objectives, ii) the replication of the two previous steps while the decision maker is not yet satisfied with the solution or additional improvement is possible. Another way to cope with MOO problems is the application of Evolutionary Algorithms, or Multi-objective Evolutionary Algorithms (MOEAs), which can be classified to Non-Elitist MOEAs and Elitist MOEAs. Evolutionary Algorithms [197], which are based on Darwin’s survival of the fittest theory, constitute stochastic optimization processes that rely on repetitive enhancement of a population of solutions.

2.3.1.2 Multi-Attribute Utility Theory

Multi-attribute Utility Theory (MAUT) is built upon the hypothesis that decision makers want to optimize a function which aggregates all their preferences, which can be denoted by the utility function U [198]. This function is not necessarily known at the beginning of the decision process, so the decision maker needs to construct it first. In MAUT, the overall evaluation v(x) of an object x is defined as a weighted addition of its evaluation with respect to its relevant value dimensions.

∀ a, b ∈ A: a P b ⇔ U(a) > U(b) : a is preferred to b,

∀ a, b ∈ A: a I b ⇔ U(a) = U(b) : a and b are indifferent.

With utility function, the preference of the alternatives is calculated. It involves several criteria, with which the calculation of the global utility of an alternative is achieved. The utility score measures the level of well-being obtainable to the decision maker by the alternatives [199].

2.3.1.3 Analytic hierarchy

Analytic Hierarchy Process (AHP), which was developed by Saaty [200-202], deals with multiple usually contradictory and subjective criteria. In AHP, the main focus is on building the hierarchy of criteria and determining the alternatives. The AHP hierarchy structure entails the goal, the alternative courses of actions to reach the goal, and the criteria and sub-criteria on which they are evaluated [203]. The AHP process is comprised the following phases: the definition of the relative weights of the criteria and the designation of the relative rankings to the alternatives. In this approach the relative scales are resulting from pairwise comparisons [203]. The global score for each alternative is calculated by:

$$G_a = \sum_{c=0}^{n} W_c \times S_{a,c}$$

In which *a* is the alternative, *c* is the criteria, *g* is the global score of the alternative, *w* is the criteria weight and *s* is the alternative score.

2.3.1.4 Outranking methods

Within the multi-criteria methods, Outranking Methods (OMs) utilize preference relations, called outranking relations, between alternatives on specific criteria to support the decision-making process and they were designed to overcome the difficulties faced by the value function approach, especially when facing practical problems or in ambiguous problems. The outranking techniques originate from the social choice theory [182].

Outranking relations were first utilized in multiple criteria decision aid by Roy in the ELECTRE (Elimination et Choix Traduisant la Réalité) methods [183]. According to the definition of outranking relation by Roy, it is described as a binary relation S on a set of alternatives, X, in which xSy, if there are enough arguments to support that x is at least as good as y, while there is not any significant argument against that statement. In the majority of OMs, the outranking relation is built through a series of pairwise comparisons of the alternatives with appropriate procedures (for instance [9, 186]) to achieve the final evaluation outcome. The most widely used OMs are ELECTRE and PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations). The ELECTRE methods are non-compensatory (i.e. an extremely bad value in a criterion cannot be compensated by an extremely good value at another criterion).

The PROMETHEE family of OM includes: PROMETHEE I (partial ranking), PROMETHEE II (complete ranking), PROMETHEE III (based on intervals), PROMETHEE IV (continuous case) [190], PROMETHEE V (MCDA including segmentation constraints) [189] and PROMETHEE VI (sensitivity tool) [193], as well as GAIA (visual interactive module) [192], PROMETHEE GDSS (group decision-making) [188], PROMETHEE TRI (sorting problems) and PROMETHEE CLUSTER (nominal classification) [187]. The starting point of the PROMETHEE is the decision table. In this method, the pairwise comparison between all the alternatives for each criterion takes place. The preference index corresponds to the global degree of preference between two alternatives. $\pi(a,b) = \sum_{h=1}^{k} P_h\,(a,b)$, where a, b are the alternatives. The preference index can take values between 0 and 1. The method also involves two outranking flows, a positive $\varphi^{+}(\alpha)=\frac{1}{n-1}\sum_{x\in A}\pi(a,x)$ and a negative one $\varphi^{-}(\alpha)=\frac{1}{n-1}\sum_{x\in A}\pi(a,x)$, which assist the alternatives' ranking. The positive outranking flow correspond to the level in which an alternative outranks all the other alternatives, while the negative flow measures how much an alternative is outranked by the rest alternatives. OMs and as a direct consequence the PROMETHEE methods can deal with both quantitative and qualitative criteria. Among the advantages of PROMETHEE is that it can handle ambiguous and fuzzy data. The PROMETHEE methods can be tedious and problematic to overview in case of many criteria. Moreover, in PROMETHEE methods the ranking reversal phenomenon occurs, when new alternatives are introduced. Compared to ELECTRE methods, PROMETHEE methods have several differences on the construction of the relations between the alternatives, the criterion model, as well as the ranking procedure.

2.3.1.4.1 ELECTRE Methods

ELECTRE methods, which exploit outranking relations [9], can be categorized in choosing, sorting and ranking problematic [11]. The methods that correspond to the category of choice problematic are ELECTRE I, ELECTRE Iv (e.g. ELECTRE I veto) and ELECTRE IS, while ELECTRE II, ELECTRE III and ELECTRE IV methods are suitable for ranking, while the only method of the ELECTRE family that responds to the sorting problematic is the ELECTRE TRI [9].

The choice problematic is responded by the ELECTRE family, by the following methods ELECTRE I, ELECTRE Iv and ELECTRE IS. ELECTRE I method is a basic method that should be selected in cases where all the criteria are expressed in numerical values with identical ranges. In ELECTRE I when the actions set up a cycle, they are considered to be indifferent, which is criticized. ELECTRE IS was designed to respond to the aforementioned problem. ELECTRE Iv, which is ELECTRE I with veto threshold, allows heterogeneity on the ranges of the values. ELECTRE IS introduces pseudo-criteria instead of true criteria and is a generalization of the ELECTRE I. ELECTRE IS was designed for imperfect data.

The ELECTRE methods that deal with the ranking problematic are the following ELECTRE II, ELECTRE III and ELECTRE IV. ELECTRE II was the first ELECTRE method, which is developed specifically for the ranking problematic and it was also the first ELECTRE method built upon an embedded outranking relations sequence. In the ELECTRE II there are two outranking relations, a strong outranking relation and a weak one, and two respective concordance levels. ELECTRE III was designed to improve ELECTRE II. It was developed to also handle inaccurate, imprecise, uncertain or ill-determined data. ELECTRE III will be further described in the section 2.3.1.4.1.1 ELECTRE III method. No weights for the criteria are introduced in ELECTRE IV. Also, In ELECTRE IV a set of five embedded outranking relations is constructed.

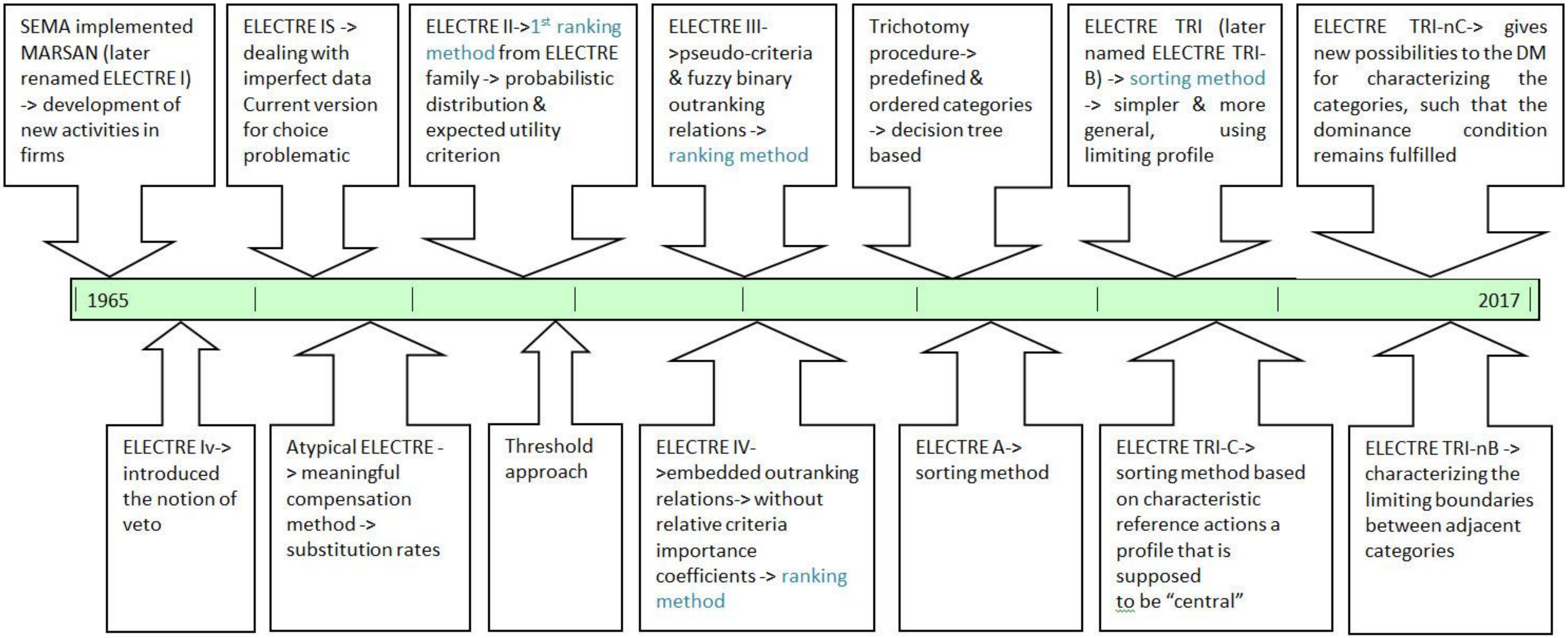


Figure 6 – ELECTRE methods timeline

ELECTRE A, ELECTRE TRI, ELECTRE TRI-B, ELECTRE TRI-V, ELECTRE TRI-C and ELECTRE TRI-NC aim to provide solution to the sorting problematic. ELECTRE A constitutes the basis of the ELECTRE TRI methods. In ELECTRE TRI approach, the categories are ordered from the worst to the best and each category must be characterized by a lower and an upper profile. In ELECTRE TRI C, each category from a completely ordered set is defined by a single characteristic reference action, which is co-constructed through an interactive process. ELECTRE TRI nC is a generalization of the ELECTRE TRI C method. ELECTRE TRI-B (ETRI-B) has two versions called "pessimistic" or "pseudo-conjunctive" and "optimistic" or "pseudo-disjunctive".

2.3.1.4.1.1 ELECTRE III method

ELECTRE III aimed to ameliorate the ELECTRE II method. ELECTRE III, which employs pseudo-criteria rather than true criteria, can manage data that is ambiguous, inaccurate, imprecise, or unclear [9]. The outranking method starts with the decision matrix, which exhibits the performance of the alternatives [10] and it consists of rows and columns of values. The matrix is useful for examining large masses of decision factors and assessing each factor's relative significance. The output of the analysis is an outranking relation on the set of alternatives. An alternative *a* outranks an alternative *b* if there is a strong enough argument to support a conclusion that *a* is at least as good as *b* and no strong argument against, bearing in mind all the available information concerning the problem and the preferences of the decision maker [10]. In ELECTRE III the outranking relation is considered as a fuzzy relation [9].

Considering two alternatives *a* and *b*, four situations may occur:

- aSb and not bSa, i.e., aPb (*a* is strictly preferred to *b*).
- bSa and not aSb, i.e., bPa (*b* is strictly preferred to *a*).
- aSb and bSa, i.e., aIb (*a* is indifferent to *b*).
- Not aSb and not bSa, i.e., aRb (*a* is incomparable to *b*).

Concordance principle: If *a* is demonstrably as good as or better than *b* according to a sufficiently large weight of criteria, then this is considered to be evidence in favor of *a* outranking *b*. Discordance principle: If *b* is very strongly preferred to a on one or more criteria, then this is considered to be evidence against a outranking b.

2.3.1.4.1.2 Terms

The terms that are related to the ELECTRE III method and are required to compute the outranking relations are referred and thoroughly described in the subsequent section.

- **i**: index labeling a criterion.

- $\boldsymbol{g_i(a)}$: individual partial preference function of the alternative a with regard to the criterion i.

- $\boldsymbol{w_i}$: weight of the criterion i.

- **Preference threshold** [p_i]: is a difference above which the decision maker strongly prefers a management alternative over all for the criterion i. Alternative b is strictly preferred to alternative a in terms of criterion i if $g_i(b)$ > $g_i(a)$+ p($g_i(a)$).

- **Indifference threshold** [q_i]: is a difference beneath which the decision maker is indifferent between two management alternatives for the criterion i. Alternative b is weakly preferred to alternative a in terms of criterion i if $g_i(b)$ > $g_i(a)$+ q($g_i(a)$).

- **Veto threshold** [v_i]: blocks the outranking relationship between alternatives for the criterion i. Alternative a cannot outrank alternative b if the performance of b exceeds that of a by an amount greater than the veto threshold, i.e. if $g_i(b) \geq g_i(a) + v_i(g_i(a))$.

- **Concordance index** [C(a,b)]: measures the strength of support, given the available evidence, that a is at least as good as b considering all criteria. C_i(a,b): concordance index over alternative a and b with regard to the criterion i.

- **Discordance index** [D(a,b)]: measures the strength of the evidence against this hypothesis. D_i(a,b): discordance index over alternative a and b with regard to the criterion i. It aims at considering the fact that a criterion g_i is more or less discordant with the assertion aSb. When the criterion g_i put veto in the outranking relation, the discordance index is maximal and when the criterion $g_i$is not discordant with the outranking relation, the discordance index reaches its minimal value. To compute the discordance in the intermediate stage, we admit that its value is grows proportionally to the difference $g_i(b)$- $g_i(a)$ [9].

- Credibility index [S(a,b)]: measures the strength of the claim that "alternative a is at least as good as alternative b". When the D_i(a,b)=1, it means that the S(a,b)=0, since the C(a,b)$<$ 1. The credibility index is based on the following principles: i) When there is not any discordant criterion, the credibility of the outranking relation is equal to the comprehensive concordance index. ii) When a discordant criterion enables the veto, then the outranking relation is not credible, therefore the credibility index is null. iii) Otherwise, when the concordance index is lower than the discordance index on the discordant criterion, the credibility index is lower than the comprehensive concordance index, due to the opposition effect on the specific criterion. [9] The credibility index corresponds to the concordance index weakened by the veto power.

2.3.1.4.1.3 Algorithm

In this section the steps of the ELECTRE III procedure are described.

1) The start point of this procedure is the decision matrix. The parameters that are required by the ELECTRE III and must be determined in order for the algorithm to proceed are p_i, q_i and v_i.

2) The next step is the computation of the concordance index for each criterion:

$$C_i(\text{a,b}) = \begin{cases} 0, \text{ if } g_i(b) \geq g_i(a) + p_i(g_i(a)) \\ 1, g_i(b) \leq g_i(a) + q_i(g_i(a)) \\ \frac{g_i(a)+p_i(g_i(a))-g_i(b)}{p_i(g_i(a))-q_i(g_i(a))}, \text{ otherwise} \end{cases}$$

3) Then the overall concordance index must be calculated:

$$\text{C(a,b)} = \frac{\sum w_i C_i(a,b)}{\sum w_i}$$

4) The subsequent step is the estimation of the discordance index for each criterion:

$$D_i(\text{a,b}) = \begin{cases} 0, \text{ if } g_i(b) \leq g_i(a) + p_i(g_i(a)) \\ 1, g_i(b) \geq g_i(a) + v_i(g_i(a)) \\ \frac{g_i(b)-g_i(a)-p_i(g_i(a))}{v_i(g_i(a))-p_i(g_i(a))}, \text{ otherwise} \end{cases}$$

If no veto threshold (v_i) is specified D_i(a,b)= 0 for all pairs of alternatives.

5) Followed by the calculation of the credibility index:

$$\text{S(a,b)} = \begin{cases} C(a,b), if \quad D\_i(a,b) \leq C(a,b) \; \forall \, i \\ \text{C(a, b)} \prod_{D_I(a,b)>C(a,b)} \frac{1-D_i(a,b)}{1-C(a,b)}, \text{otherwise} \end{cases}$$

If no veto thresholds (v_i) are specified S(a,b) = C(a,b) for all pairs of alternatives.

6) The last step of the procedure is the definition of the rank order:

i. First the descending distillation takes place:

6.1) Determine the maximum value of the credibility index: $\lambda_{max} = maxS(a, b)$.

6.2) Calculate $\lambda = \lambda_{max} - (0{,}3 - 0{,}15\lambda_{max})$. Where -0.15 and 0.3 are the preset up values of distillation coefficients, α and β.

6.3) For each alternative α determine its λ-strength, i.e. the number of alternatives *b* with S(a,b) > λ

6.4) For each alternative *a* determine its λ-weakness, i.e. the number of alternatives *b* with (1- (0.3 - 0.15λ)) * S(a,b) > S(b,a)

6.5) For each alternative determine its qualification, i.e. the difference between λ-strength and λ-weakness.

6.6) The set of alternatives with largest qualification is called the first distillate (D1).

6.7) If D1 has more than one alternative, repeat the process on the set D1 until all alternatives have been classified. If there is a single alternative, than this is the most preferred one. Then continue with the original set of alternatives minus the set D1, repeating until all alternatives have been classified.

ii. Then, the ascending distillation:

This is obtained in the same way as the descending distillation but at step 6.6, the set of alternatives have the lowest qualification forms the first distillate.

iii. And ultimately, the final ranking:

There are several ways how to combine both orders. The most frequent is the intersection of two outranking relations: *aRb* (*a* outranks *b* according to *R*) if and only if *a* outranks or is in the same class as *b* according to the orders corresponding to both relationships.

2.3.2 Comparison between Multiple criteria decision making methods

ELECTRE III's results may be subjective (like many other methods - ELECTRE, PROMTHEE & AHP methods) [221], since it vastly depend on the opinion and the perception of the decision maker that set the variables of the problem (weight and thresholds), but this is exactly its benefit. Each decision maker have different perception on the situation at hand and in order to better assist him in the decision making process, we provide a highly personalizable method that will pinpoint the best solution for the problem, according to his preferences and anticipations.

2.4 Visual analytics

The term visual analytics has emerged in 2004. Nevertheless, earlier efforts had led to the generation of this research area, such as the shift of focus from confirmatory to exploratory data analysis, which was first introduced in 1977 [152]. In confirmatory data analysis, charts and visual representations are utilized for data presentation, while exploratory data analysis also allows data interaction. The subsequent step towards visual analytics was the introduction of visual data exploration and visual data mining, in which the user had been taken into account in knowledge discovery and data mining using interactive visualizations and knowledge transfer [150]. Visual data exploration constitutes a human-guided process that enable insights over data and consequently the generation of new hypotheses [153, 204], visual data mining denotes the search and analysis of databases to retrieve information and combines data mining and information visualization techniques [154, 205].

Visual analytics is the discipline of *"analytical reasoning supported by interactive visual interfaces"* [100] and is interdisciplinary, conglomerating several related research areas, including visualization, data mining, data management, data fusion, statistics and cognition science [19]. They transform data into knowledge that is both verifiable and consistent [19]. Its key idea is to create a synergy that implicates computational power and human reasoning [140], whereas its ultimate goal is the establishment of tools and techniques for:

i) creating information and insights from large, dynamic, uncertain, and even contradictory data,

ii) detecting the anticipated and discover the unanticipated,

iii) providing assessments and

iv) presenting successfully the assessments to assist stakeholders into taking actions [19].

The Survey of Visual Analytics Techniques and Applications [208] analyses and groups the available methods into the following categories: space and time, multivariate, text, graph and network, etc. Each one of these categories is associated to important stages of the visual analytics process, such as visual mapping, model-based analysis and user interactions. Visual analytics are considered valuable tool for decision makers that exploits human capabilities, like flexibility, creativity, perception and particularly parallel visual processing, reasoning skills, such as adaptation and accommodation [156], superior decision making and background knowledge, to balance and overcome the human cognitive deficiencies, like limited working memory. They integrate them with the capacities of modern computers in order to provide solutions to complex problems [155]. Thus, achieving the most effective results and empowers DMs to make informed decisions [206-207].

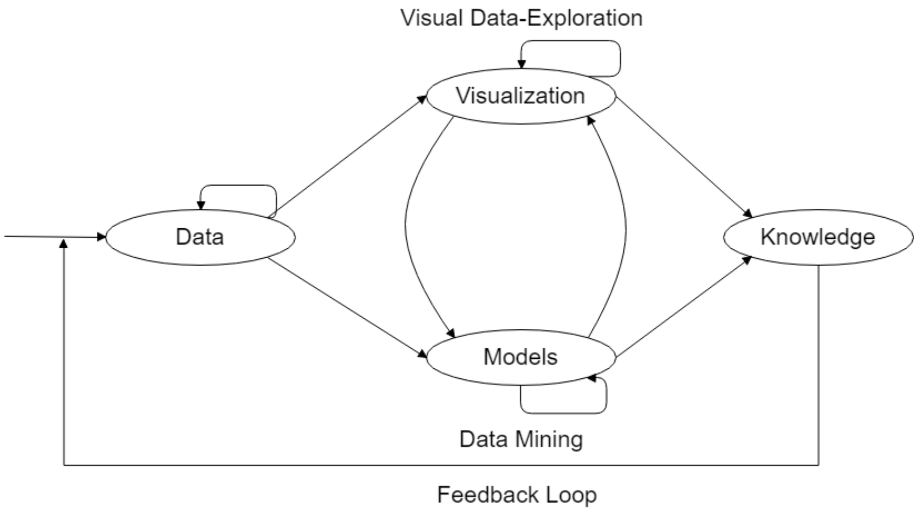


Figure 7 - Combination of visual and automatic data analysis [19]

Visual analytics also respond to the information overload problem, which describes such a volume of information that cannot be assimilated by the users or large amounts of unwanted information, some of which may be important to the users [149]. This problem refers to the danger of being overwhelmed by data that is either irrelevant to the current task, incorrectly processed or inappropriately presented [19, 150]. However, in order to overcome the obstacle of information overload, the required information must be available at the right time [19, 150]. Visual analytics transform information overload into an opportunity. Their aim “is to make our way of processing data and information transparent for an analytic discourse” in an interactive way, similar to the way that information visualization has altered our perspective about databases [19]. According to Keim, the mantra of visual analytics is the following "Analyze first, Show the Important, Zoom, filter and analyze further, Details on demand" [211]. The visual analytics mantra is based on the Shneiderman visual information seeking mantra "Overview first, Filter and zoom, Details on demand" [210].

2.4.1 Visual analytics and visualization

Visual analytics is more than visualization [19]. Unlike visualizations, visual analytics gives higher priority to data analytics from the beginning and throughout the sense making loop [19]. Information visualization has been used i) as a medium to persuade, ii) to augment cognition, iii) better discover the information, iv) to visually represent information v) enable the users to interact with the information, vi) to ameliorate the decision making process and vii) effectively communicate information [16, 18, 20, 21, 22 and 23]. An advantage of well presented data visualization is the amount of information that can be quickly inferred by the user [27], to focus on a smaller amount of information and to discover segments of data to scrutinize [28], since *"a picture is worth a thousand rows [of data]"* [80]. Furthermore, according to John Tukey: *"The greatest value of a picture is when it forces us to notice what we never expected to see"* [268]. Some of the reasons that favor the utilization of visualizations as an information medium are the following: visualization and graphics are the most engaging form of outputs [139], they reveal patterns on the data, they are easier comprehendible and they simplify large, intricate and abstract data.

Visualization can be distinguished into scientific and information visualization. Scientific visualization is a subcategory of visualizations that generates graphical representations of scientific phenomena based on quantitative data [17]. Some examples of early data visualizations were meant to show and explain and not to analyze [144]. Information visualization employs computer supported interactive visual representations of data to augment cognition [12] and assists the extraction of insights from the collected data [151]. Information visualization systems contribute in cases where the users have more meaningful questions about the dataset, or even when they do not know the questions to be asked [28]. The four stages of visualization comprise of the collection and the storage of data, the preprocessing of the data in order to make them comprehensible, the display hardware and the graphics algorithms that produce an image on the screen and the human perceptual and cognitive system (the perceiver) [27]. As defined by Bill Ferster, “Interactive visualization is the process of letting primary sources of information communicate directly with viewer to support inquiry in a visual, compelling, and interactive manner” [17]. The combination of interactive computer graphics, the large existing data sources, the Internet and their current advances have led to introduction of interactive visualization [17].

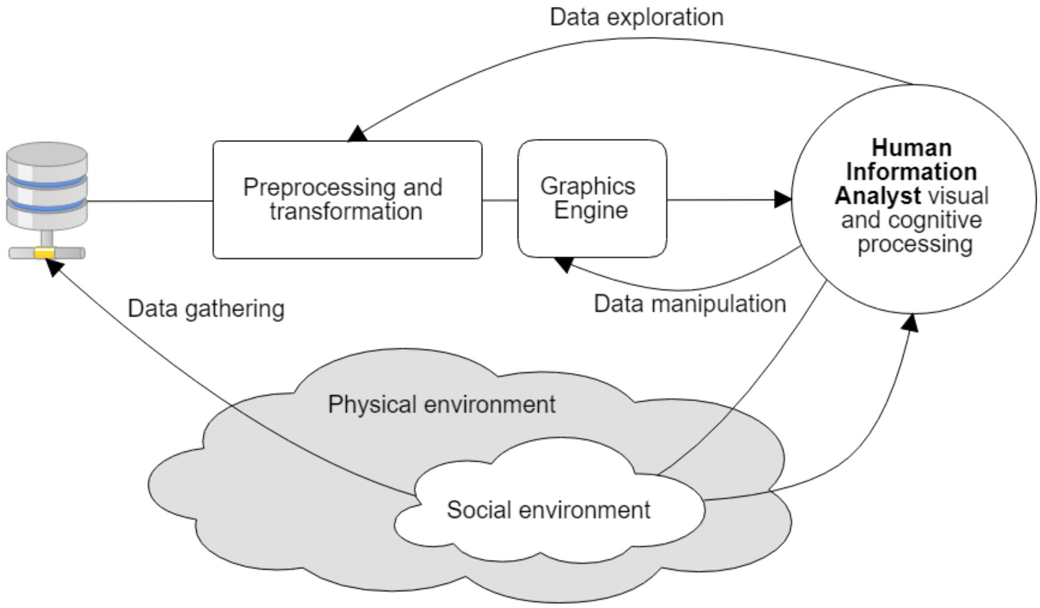


Figure 8 - A schematic diagram of the visualization process [27]

2.4.2 Visual analytics of multidimensional datasets

The exploration of large multivariate networks and datasets in general is still a challenge [142]. Visualization research has been focused on data exploring and analyzing [144]. Since visualizations have been also utilized more and more, the need to also support decision making has been arisen [144]. Exploring, analyzing and decision making over large datasets are intricate tasks [143] and high dimensional and multifaceted datasets necessitate coordination and assistance to the user [209]. Moreover, the simultaneous exploration of the data can provide greatest insights [142]. Visual analytics distinguish the benefits and challenges of these datasets and contribute to complex data analysis [140]. Furthermore, visual analytics of multifaceted data is considered as an active research area, in which various methods are utilized so as to discover and recognize distributions and connections among different data dimensions. These before mentioned methods can be categorized as: projection-based methods, relying on dimension reduction techniques, and visual methods, based on visual layouts. The latter category, visual methods, manipulate visualization layout algorithms, like parallel coordinate plots (PCPs) and pixel-oriented methods so as to draw multivariate data for analysis.

2.4.3 Visual analytics techniques

The types of the data that can be visualized vary and can be one-dimensional data, two-dimensional data, multidimensional data, text and hypertext, hierarchies and graphs, algorithms and software [223]. The interaction techniques that can be implemented in the visual representations are interactive projection, filtering, zooming, interactive distortion, linking and brushing [223]. Several visualization techniques can be used to present the data, including:

- *Standard 2D/3D* techniques, such as bar charts, x-y plots, histogram, scatter plot and multiple view.
- *Geometrically transformed* visual representations that reveal engaging transformations of multidimensional data sets [223], for instance: landscapes, parallel coordinates, star coordinates table lens tours.
- *Icon-based, or glyph-based* techniques in which the dataset is portrayed by visual objects [227], (icons, glyphs), such as needle icons and star icons, star plot, stick figure, Chernoff faces and color icons.
- *Pixel-based* techniques, which encode data based on the colored position in 2D space [225], for example the recursive pattern, circle segments techniques, graph sketches, space filling, pixel bar chart and spiral technique.
- *Hierarchical and graph-based* techniques display the information space as a hierarchy or a graph [228].
- *Stacked* visual representations in which images are embedded recursively inside a higher-level image [226], such as treemaps, dimensional stacking and hierarchical axis.

Especially, for visualizing multivariate data, the methods that can be used are:

- *Projection-based*, or *dimension reduction* methods, which find interesting projections of high dimensional data in low dimensional space, such as multidimensional scaling (MDS), principal component analysis (PCA), local affine multidimensional projection (LAMP) and similarity tree technique [208].
- *Visual methods*, which utilize visualization algorithms to present multivariate data, like pixel-oriented methods, scatterplot matrices and parallel coordinate plots (PCPs). The latter two can also be considered as projection-based techniques, due to the fact that they transform high dimensional data in the 2D space [208].

Each person exploits different decision support means to form, empower, rectify, or even change a decision [143]. A significant feature when visualizing data is the interaction, since it not only allow the presentation of the data, but also enables altering the presentation, which accelerates the analysis and makes it more effective [144].

2.4.4 Human cognition and perception

The vision is the predominant sensory receptor, since the 70% of the sensory receptors are located in the eye and the 40% of the brain is used for visual processing. Humans perform better when information is presented to them in visual form, compare to giving the same information in textual form [232]. Within 100ms a viewer can make sense of a visual scene, while it takes additional 300ms to retain the information presented in the scene [229]. The computer can support the user by making the information available in a relevant context and by pinpointing the information that may be overlooked, when the complexity of a given task transcends the ability of the user to handle the required information, or a cognitive barrier is attained [155]. However, the ability to visualize is surpassing the understanding of the thinking system to which the visualizations aim [155]. Even though the fact that visual analytics is gaining increasing interest as a scientific field, the underlying complex analytic and reasoning process is usually neglected and higher cognition processes, such as judgment and decision making, are regarded as a “black box” [212].

Visual representations must be informative, engaging and unbiased [139]. Although, visual analytics and visualizations contribute to the deeper understanding of the data, their design and utilization should be undertaken with caution. The use of compelling graphics can cause cartohypnosis, a pseudo-impression of truth, which may favor specific information and thus generate biases in the perception of the users [139]. Chart junk corresponds to non-data, such as graphical embellishments, and redundant data in a visual representation, adds no value to the visual representation and can be distracting and harmful [214]. However, graphical embellishments, when used in moderation, can promote the visualization's effectiveness by engaging users, by making the presented information more memorable and by emphasizing specific parts of information. Embellishments enhance the effectiveness of visual representations only if they do not create distractions or misrepresentation [213].

2.5 Semantic web

Semantic web is the extension of the World Wide Web (WWW). The WWW is a web of documents, whereas the semantic web is a web of interlinked data. It is readable and processible by machines, due to metadata, which are data that describe the well-defined meaning of structured data, hence the term semantic. The semantic web principles mandate for reuse of ontologies and data [215]. Semantic web globalizes the knowledge representation, like the Web had glogilized the hypertext [216]. The semantic web stack (Figure 9) consists of all the languages and standard technologies required to establish the Semantic Web. It can be categorized to the following categories hypertext web technologies, standardized and unrealized Semantic Web technologies.

Hypertext Web technologies are used without any change provide in the semantic web and include i) identifiers (Internationalized Resource Identifier – IRI, Uniform Resource Identifier - URI), ii) character set (Unicode), iii) syntax, (XML - eXtensible Markup Language, xmlns - XML Namespaces). The identifiers are required to uniquely distinguish the semantic web resources, in order to enable the resources' handling in the top layers of the Semantic Web stack. The character set, UNICODE, provides representation and manipulation of the text in many different languages. As far as it concerns the syntax, XML is a markup language, designed to be both human- and machine-readable that facilitates the sharing of structured data, while xmlns enables the use of markups from different sources and avoids element name conflicts.

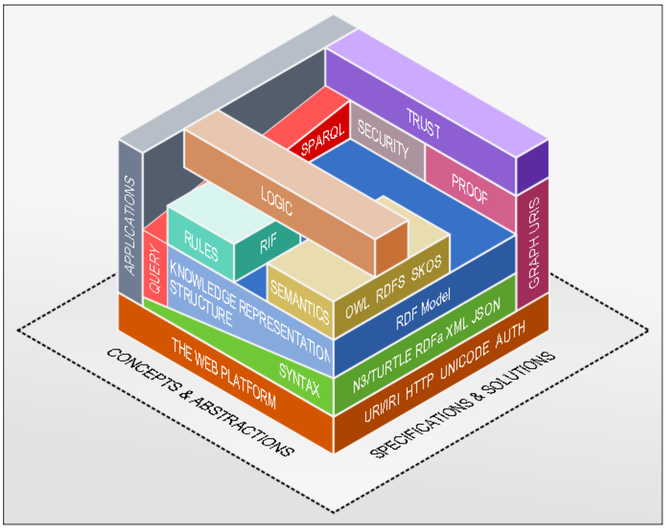


Figure 9 - The semantic web stack

Standardized Semantic Web technologies comprise technologies standardized by W3C especially for semantic web applications and include: i) data interchange (RDF - Resource Description Framework), ii) taxonomies (RDFS - RDF Schema), iii) querying (SPARQL - SPARQL Protocol and RDF Query Language), iv) ontologies (OWL - Web Ontology Language) and v) rules (RIF - Rule Interchange Format /SWRL - Semantic Web Rule Language). RDF is a framework for creating statements in a form of so-called triples and represents information about resources in graphs, while RDFS provides the data-modeling vocabulary for RDF, with RDFS it is possible to create hierarchies of classes and properties. SPARQL is a RDF query language - it can be used to query any RDF-based data (i.e., including statements involving RDFS and OWL). Querying language is necessary to retrieve information for semantic web applications. OWL extends RDFS by adding more advanced constructs to describe semantics of RDF statements. It allows stating additional constraints, such as for example cardinality, restrictions of values, or characteristics of properties such as transitivity. It is based on description logic and so brings reasoning power to the semantic web. RIF/SWRL is a rule interchange format. It is important, for example, to allow describing relations that cannot be directly described using description logic used in OWL.

Unrealized Semantic Web technologies contain technologies that are not yet standardized or contain just ideas that should be implemented in order to realize Semantic Web, including cryptography, unifying logic, proof and trust. Cryptography is important to ensure and verify that semantic web statements are coming from trusted source, for instance to verify identity or to allow access, etc. The requirement of cryptography can be satisfied by utilizing certain technologies, such as digital signatures, public-key encryption/decryption algorithms, or secure protocols [220]. Unifying Logic layer corresponds to an interoperability layer that aims to integrate the lower-level technologies with a unifying language. Proof should be given to clients by software agents so as to validate the procedure or information. Trust declares the sources of information that are trustworthy, as well as level of access of each agent to the data. User interface and applications is the final layer that permits humans to make use of semantic web applications.

2.5.1 Semantic organization of the data

Numerous studies have shown that it is of vital importance to transform relational data into Linked Data format [62, 63, 64]. Ontologies are used to ease the transition between relational databases and Linked Data, since they express the relationships among concepts within a particular domain and provide the structure of Linked Data [65]. Among the many benefits of Linked Data are the subsequent: the reproducibility [72], the shareability, the extensibility, the re-usability and the fact that applications can deal with them directly [59].

2.5.2 Ontology

Ontologies facilitate the publication of machine readable data [15]. According to Gruber and refined by Studer: “an ontology is an explicit and formal specification of a conceptualization” [29, 30], while the notion of sharing ontologies was firstly introduced by Brost [33]. They endow with a shared and common understanding of a domain [32]. An ontology can be described as a logical theory that clarifies the intended meaning of a formal vocabulary [217] and corresponds to a data model with which we represent a domain, its objects and the respective relations between them. An ontology includes instances (individuals), classes (concepts), attributes (properties), relationships, function terms, restrictions, rules, axioms and events.

Ontologies can be distinguished to upper and domain ontologies. Upper ontologies, which are also called top-level ontology and foundation ontology, consists of very general terms that are common across multiple domains to support interoperability and constitute the foundation for more specific domain ontologies [218]. On the other hand, a domain ontology, otherwise known as domain-specific ontology, describes a single domain and represents the meaning of the terms as they occur in the domain at hand.

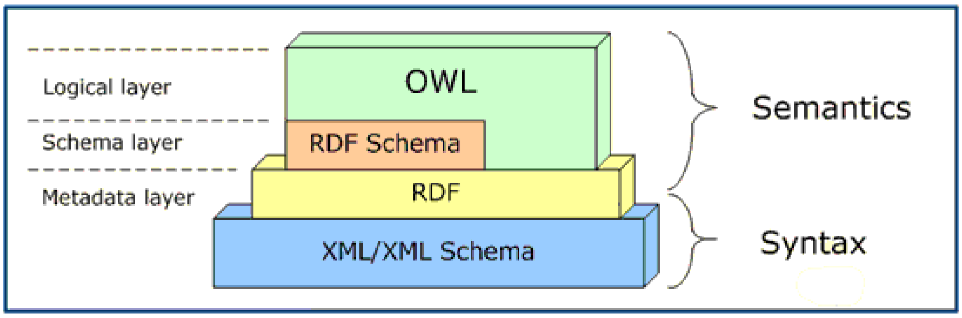


Figure 10 - Ontology languages in the Semantic Web Architecture [34]

XML/XML schema, RDF, RDF Schema and OWL are ontology languages, as described in Figure 10. Extensible Markup Language (XML) is a markup language, in which documents are encoded in human and machine readable format via a set of rules. XML schema imposes constraints on the syntax and structure of valid XML documents and also offers basic vocabulary and structuring mechanisms for delivering information in XML format. XML is syntax, while Resource Description Framework (RDF) is a standard model for data interchange on the Web that has several syntaxes, including Turtle, N3, XML, also called RDF/XML. RDF expedites data merging irrespectively of the schemas, whether they differ or not, while it also promotes the schemas' evolution without calling for changes in the data consumers. RDF Schema (RDFS) utilizes the RDF representation data model and extends the basic RDF vocabulary. It endows basic features for ontology description, called RDF vocabularies, which structures RDF resources. However, RDF and RDFS can represent merely a part of ontological knowledge [222]. OWL builds on RDF and RDF Schema, and employs RDF's XML syntax, but incorporate richer expressiveness [222] and represents rich and complex knowledge. OWL is a computational logic-based language [223].

2.5.3 Schema and ontology matching

2.5.3.1 Schema matching

Schema matching is a rudimentary problem in many application domains, from data integration data warehousing and e-commerce to semantic query processing and it concerns relational and XML databases [283]. It has been motivated by schema integration, which has been arose and studied since 1980, the goal of which has been to create a common ground on different schemas [284]. The classification of the key schema-based matching techniques is presented in Figure 11, ranging from individual matching approaches to approaches that use multiple match algorithms (matchers).

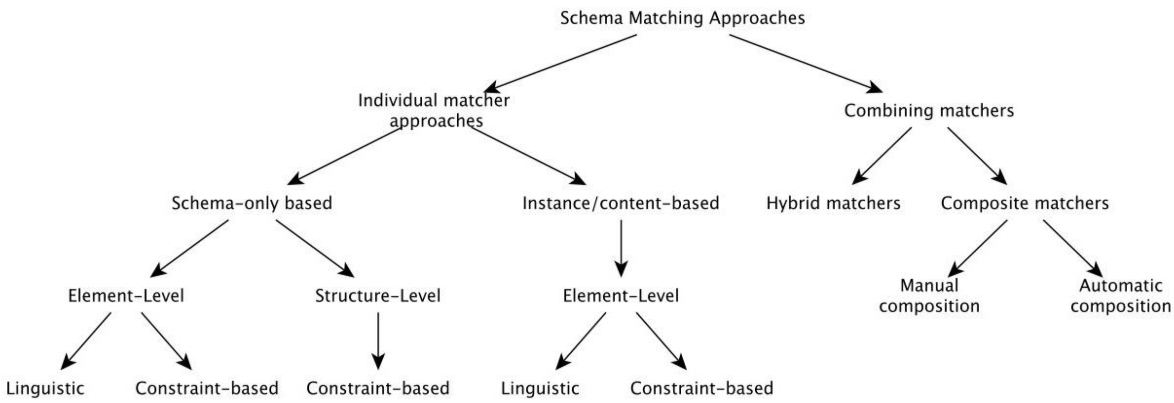


Figure 11- Classification of schema-based matching techniques [283]

2.5.3.2 Ontology matching

In ontology development, different ontologies may represent the same concepts. The heterogeneity in ontologies can derive from different approaches to conceptualization, different naming principles (same concept, different naming or same name, different concept), or different contexts. However, ontology-structured content conveyed in different ways should be unified before used. Matching process aims to find relationships or correspondences between entities of different ontologies, while the output of this process is the alignment, which is a set of correspondences between two or more (in case of multiple matching) ontologies. Correspondence is the relation supposed to hold according to a particular matching algorithm or individual, between entities of different ontologies, whereas mapping is the oriented version of an alignment.

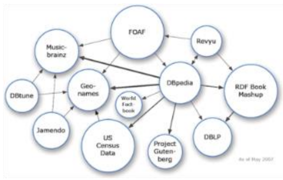
2.5.4 Linked Data and Linked Open Data

Linked Data denotes the best practices that have led to the generation of the Linked Data cloud, for publishing and connecting structured data. Linked Data is utilizes the Web to create typed links between data from different sources. The diverse sources range from different systems within an organisation to different databases of organizations in different geographical locations. Linked Data denotes data published on the Web in a machine-readable manner, its meaning is unambiguously defined, it is linked to external Linked Data datasets, and it can also be interconnected by other external data sets. Linked Data employs RDF in order to make typed statements, connecting arbitrary things, which results to the Web of Data. The main principles of Linked Data as stated by Berners-Lee (2006) are the following:

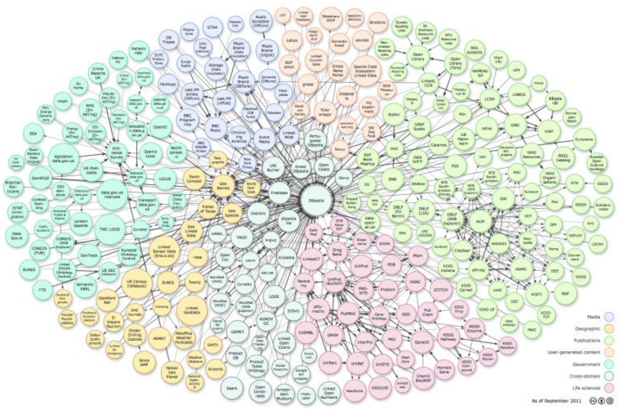
1. The usage of URIs as names for things.
2. The utilization of HTTP URIs so that the names can be looked up.
3. When someone looks up a URI, provide useful information about what a name identifies using the related standards (RDF, SPARQL).
4. Refer to other things, using their HTTP URIs, when publishing data, so that they can discover more things.

Linked Open Data (LOD) enriches Linked Data with the benefits of open access. It constitutes the adoption of the Linked Data principles and is founded in January 2007 and supported by the W3C Semantic Web Education and Outreach Group [145]. The main objective of LOD is to detection of existing open datasets; their conversion in line with the principles of Linked Data, and their publication. The Linked Open Data cloud is composed from all the available Linked Open Data interconnected datasets and has been growing continuously [59] with exponential data growth. To elaborate, since its start in 2007 and until March 2019, the Web of Data has grown up to almost 1239 interlinked datasets, with 16147 links, covering a broad range of topics [61], including media, geographic, government, publications, cross-domain, life sciences and user-generated content. Each node in the LOD cloud corresponds to a distinct dataset published as Linked Data. The arcs in Figure 12 indicate the links that exist between items in the two connected datasets. Heavier arcs denote a greater amount of connections between the datasets and bidirectional arcs declare that the external links to the other exist in each dataset.

May 2007



September 2011



March 2019

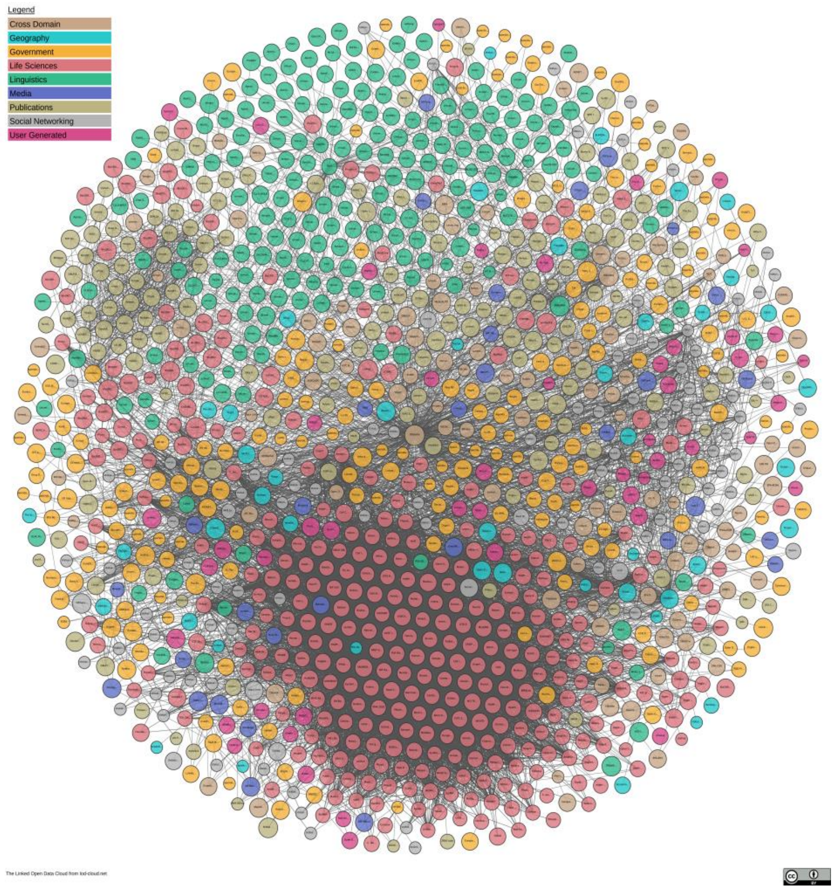


Figure 12 – LOD cloud, indicating the evolution of LOD (from 2007, to 2011 and finally to 2019), from lod-cloud.net [219]

2.6 Combining DM, visual analytics and ontologies

The decision making process and more specifically the MCDM process requires the in-depth comprehension of the data on which the decision maker would base his/her decision. As a direct consequence, techniques that provide a profounder data presentation and exploration should be considered a valuable tool for the DM.

There are a few methods that combine these scientific areas. First and foremost, IREMA decision support system has been occupied with the evaluation of faculty members of HEIs assisted by ontologies and visual analytics [252]. However, this approach implements a Data envelopment analysis algorithm, not a MCDM algorithm, and is applied in one application field. In Decision Exploration Lab (DEL) tool, decision models that depict the business domain and production rules have been modeled in an ontology to aid the decision making process. The process has been further supported by visual analytics, categorical presentation of the ontology's contents [263]. Although, the before mentioned method focuses on automated decision making and not decision support. Visual analytics and ontologies have been combined into a knowledge-assisted visualization system for bridge management, in which the complementary relationship of the two aforementioned domains was inspected [258]. Even though, the method is said to be generic, with the definition of a Problem Domain Ontology, there is no mention about the way that it is adapted to another domain. Media Watch on climate change is a public web portal composed by large archives of digital content derived by several stakeholders [265]. This approach displays the information in a visual analytics dashboard. The dashboard contains an interface for managing and tracking topics related to climate change, a variety of visualizations, such as geographic map, tag cloud, information landscape and ontology graph, as well as semantic search. This approach integrates visual analytics and semantic web technologies into decision making. However, the visualizations of semantic web compliant data are limited to keyword presentation and graph presentations of the ontology, which are helpful to understand the data, but not directly support and facilitate a decision making task. None of the aforementioned methods that combine all the three scientific areas does not support multidimensional decision making.

In another approach, risk assessment in certification and accreditation activities takes place and involves multidimensional connections on many requirements, visual analytics and ontologies to classify and categorize the certification and accreditation requirements and it should be facilitate diverse stakeholders [264]. Based on the semantics of DITSCAP (Defense Information Technology Security Certification and Accreditation Process) requirement, its relationships with other domain concepts in the DITSCAP Problem Domain Ontology (PDO) are visualized. The ontology assists in comprehending the domain. However, the process requires an expert for the instantiation of the ontology and for the proof of compliance with the requirements. Furthermore, the visualizations are difficult to understand and require some level of expertise. Additionally, the system can accommodate only this domain, it cannot be generalized. No additional exploration capabilities are provided through the ontology. The publication does not refer to the synergy of visual analytics and ontologies in this approach.

Even though the abovementioned methods conglomerate decision making, visual analytics and semantic web technologies, they differ from our method. None of these methods implement a MCDM algorithm. These methods have been applied only in one application field. In the subsequent sections, we would explore the existing methods that combine decision making techniques with visual analytics or ontologies, as well as methods that employ synergy between visual analytics and ontologies.

2.6.1 Literature review on the combination of decision making methods / MCDM and ontologies

Ontologies have been utilized in decision making to improve the decision making process, to offer structure to the data and to promote data sharing [132], or as reasoning mechanism that entails decision support capabilities [109]. The majority of such ontology-based approaches employ decision making process, whereas fewer ontology-based approaches are utilized in MCDM systems. Several approaches that combine decision making or multiple criteria decision making and ontologies use the ontology as the source of the information needed from the decision making system, while others employ ontology reasoning mechanisms to facilitate the decision making process.

2.6.1.1 The ontology as a source of information in DM

Several methods integrate data on decision making systems [114, 115 and 116]. An ontology for electrical products has been used as a mean to assimilate information from diverse systems to support decision-making [114]. In this method, the ontology assisted the input of the information from different sources to better sustain the Engineer-To-Order product design process. Another method designed a logistics decision support system based on ontology [115]. The before mentioned approach described an ontology-based architecture to integrate conflicting data among information systems and decision making systems. A technique for information assimilation has been implemented for knowledge synthesis in a distributed computing environment [116].

However, none of these methods implicates reasoning mechanisms within its core. They utilize ontologies only as a mean to structure the related information. Therefore, none of these methods is generally applicable, since they have been developed specifically for their application fields. Additionally, the presented approaches do not support the processing of multiple criteria.

2.6.1.2 Decision support facilitated by ontology reasoning mechanisms

Several decision making methods are based on reasoning mechanisms to acquire their results. In those approaches, the decision making system is replaced by an ontology-based mechanism. Among those approaches, there are generic methods [121, 122 and 123] and domain specific methods [124, 125, 126, 127, 128 and 129].

Semantic decision tables were proposed in [121]. They are based on the regular decision tables, but they are also marked up with explicit decision semantics using a domain ontology. This approach was based on the DOGMA (Developing Ontology-Grounded Methods and Applications) framework [230]. Another method presented semantic decision making facilitated by ontology-based soft sets and ontology reasoning [122]. In another method, the KAD (Knowledge-Argument-Decision) model introduced to meet the decision maker’s requirements towards knowledge exchange during argumentations [123]. Moreover, the proposed ontology model is developed based on multidisciplinary scientific areas, such as knowledge management, argumentation, collaborative decision making and multi-criteria decision aid.

An ontology-based expert system for database design was developed in [124]. They proposed the use of an ontology as a substitute of the words stored in database. Another method proposed an expert system for corporate financial rating based on ontologies [125]. In this approach, the knowledge content is separated into domain knowledge of financial statements and operational knowledge of analytical process. In another approach, an ontology-based intelligent system for recruitment was proposed [126]. An ontology was used to model the knowledge of the recruitment domain. In addition, the ontology facilitated the intelligent web portal that has been developed to pair the requirements stated in a job description with the qualifications of a candidate. A conceptual model for the industrial manufacturing process and also a proof of concept implementation were described in [127]. They utilized the ontology-based rules to capture and identify the current and the new situation of the process. Another approach [128] applied an argument-based approach for representing and reasoning clinical knowledge. They presented a logical language developed especially for their needs, while the proposed Ontology-based Argumentation Framework (OAF) has been further evaluated with a large case study related to decision making on the breast cancer treatment [231]. The use of semantic web ontology for the development of a medical expert system for the heart failure domain was described by [129].

These methods involve a decision making method only within their inference mechanism. Nevertheless, supporting decision only with ontology reasoning mechanisms is not sufficient in multiple criteria decision making. Especially, multidimensional ranking problematic necessitates a more complicated approach that leads to a more detailed solution. Even though there are general applicable methods and support only the change of application field and not the alternation of the decision making method which they use.

2.6.1.3 The ontology as a source of information of MCDM methods

Mun et al., Niaraki and Kim and Martínez-García et al. propose ontology-based systems, which are facilitated by the MCDM methods ELECTRE IS, AHP and ELECTRE III respectively [111, 117, 118, 119 and 120]. Mun et al., in their method for determining part similarity between the user requirements and the contents of a database combine ontologies with the multiple criteria decision making method ELECTRE IS [111,117, 118], whereas Niaraki and Kim described a personalized route planning system based on ontologies and facilitated by a MCDM method [119]. Their method proposed a technique for knowledge modeling employing Analytical Hierarchical Process (AHP). Martínez-García et al. proposed semantic criteria as lists of tags and conventional criteria that are used by the outranking method ELECTRE III [120]. However, these methods do not implicate reasoning mechanisms within their core, thus they do not support further exploration of the data. Moreover, the above mentioned methods are not dynamic, since they limit their application in only one domain. They also do not allow the use of another MCDM approach, since they are explicitly developed according to the MCDM method that they use and they have not modeled it within their ontology.

2.6.1.4 Multiple-criteria decision support facilitated by ontology reasoning mechanisms

Bastinos and Krisper developed a MCDM method, assisted by ontologies [109]. In their approach, the decision models were constructed by the ontology and the decision making result was obtained by a reasoning mechanism. This approach is generally applicable and provided an example on the domain of electrical power transmission. The before mentioned method was generic as far as it concerns the application field. However, it is not dynamic as far as it concerns the MCDM method. Furthermore, it provides only a reasoning mechanism and the decision making process is represented only by the rules of the ontology.

2.6.2 Literature review on multi-faceted MCDM ranking methods

MCDM approaches involve the processing of multiple variables. Usually, several of these variables have certain similarities among them. These variables can form separate profiles, which may judge the outcome of the decision making. Hence, it is important to be able to capture and express these profiles. Del Vasto-Terrientes et al. proposed an ELECTRE III hierarchical method, in which a problem was broken down into subproblems and permitted the designation of a preference model at each node of the hierarchy [130]. In the before mentioned method, all the criteria except from the root criterion are pseudocriteria, which are structured in a hierarchy composed of many generalization levels. The AHP multiple criteria decision making method divided a problem into discrete subproblems in different levels of hierarchy [131]. However, this approach aims to rank domains that are consisted by multiple levels of hierarchy, while the MOBVR approach clusters the criteria based on their similarity. Nevertheless, the existing multifaceted MCDM methods consider multiple levels of criteria [130, 131], rather than clustering of the criteria that we consider in our method.

2.6.3 Literature review on the combination of decision making and visual analytics

The process to derive decisions from data is intricate [150]. However, displaying the result, without disclosing the process may hide dangers. The key is to communicate the knowledge on which the decisions are based [150]. Users that have to make a decision via a visual interface perform better compared to users basing their decisions on a text-based interface in both low and high complexity tasks [233]. Not only the field of visual decision analytics, as visual analytics for decision making is referred in [234], is growing constantly, but also visual analytics is becoming of vital significance for effective and efficient decision making.

Visual analytics has been applied in decision making systems to support a wide range of application fields and decision tasks. Visual analytics have been applied in geospatial information to support for spatial decision support, a field called GeoVisual Analytics (GVA) in numerous studies [235, 236, 237, 238, 246], from simulations models that use Geographic and Meteorological Information to visualize natural phenomena, such as environmental hazards, in real time [237], to crisis management for emergency support [246]. Moreover, visual analytics has also supported decision making on economic [243, 244, 247] and health care sector [245, 249], as well as on environmental [251] and maritime decision making [248]. Another domain in which visual analytics has been employed is the education, with applications on a variety of decision tasks, including the facilitation of dynamic diagnostic decision-making of teachers in classrooms [242], learning analytics [250]. The aforementioned methods do not employ semantic web technologies to facilitate the decision making process.

Even though multiple criteria decision making could benefit from interactive visualization, few tools are focused explicitly on this need [141]. Spatial multiple criteria decision analysis that incorporates GIS (Geographic Information System) and MCDM methods, such as spatial analysis and social network analysis [235]. An interactive visualization technique for weight-based MCDM, WeightLifter, supports the exploration of weight spaces and can host up to ten criteria [141]. Visual analytics has been also used in a multiple criteria decision analysis system for textile composite materials selection [239]. Visual analytics have been also used in MCDM approaches for energy efficient building design [240, 241]. The Multi-Objective Optimization and Visualization Tool (MOOViz) was developed in the context of the EU project CONSESUS (Confronting social and environmental sustainability with economic pressure) and aimed to develop a MCDM tool with the assistance of visual analytics tested in two case studies and more specifically, Biofuels and Climate Change and Transportation Networks. Despite the fact that WeightLifter and MOOViz are generic MCDM methods that can be implemented in any application field, none of these methods involves ontologies in the decision making process. Even though visual analytics have been applied in multivariate decision making, none of the above methods considers semantic web technologies to support the decision making process like the proposed method.

Visual analytics have been employed in decision making and multivariate decision making to aid the decision makers through the process. However, according to the literature, there is only one method that utilizes both visual analytics and semantic web technologies to support decisions, but it is not generally applicable. Moreover, two methods that utilize visual analytics in MCDM and are generic, do not involve ontologies within their architecture.

2.6.4 Literature review on the combination of visual analytics and ontologies

Visual Analytics can contribute in interpreting Semantic Web, in simplifying and ameliorating the communication of the meaning of the semantics. According to Keim [262], novel Visual Analytics methods are necessary in order to unravel semantic heterogeneity and discern intricate relationships [262]. Likewise, semantic web can accommodate intricate relationships within data sets that aid decision-centered visualization.

Visual analytics have been utilized in presentation of ontologies in the EU project CODE (Commercially Empowered Linked Open Data Ecosystems in Research), in which RDF data cubes [253], which is a way to publish multidimensional data, like statistics, that can be connected to related data sets and concepts [254]. Visual analytics have been used in displaying and exploring large semantic graphs [255]. WebTheme combines visual analytics and Semantic Web by providing understanding of semantics of large collections of information [256]. A minimalistic ontology was utilized for the categorization of Tweets in order to acquire knowledge about people's everyday activities and habits and display it via spatiotemporal visual analytics [257]. In another approach, entity timelines have displayed visual analytics of entities that co-occur with a specific entity in the same Web page or document. The approach utilize ontologies to retrieve the before mentioned information [259]. Another method focuses on ontology matching with the assistance of visual analytics multi-linked views [260]. DIVE (Data Intensive Visualization Engine) is a graph-based visual analytics framework capable of presenting Big Data, which utilizes datanode ontologies [261]. Datanodes emulate traditional object instances and can be within an ontological network or graph.

According to literature, visual analytics and ontologies have been used in combination. However, the before mentioned methods do not implement a decision making algorithm, let alone a MCDM algorithm.

2.6.5 Summary and conclusion

As derived from the literature, visual analytics and ontologies have been utilized in advantage of decision making. Several methods employ ontology-based decision making, while other approaches enhance the decision making process with visual analytics. Fewer methods involve both visual analytics and ontologies in the decision making, but none of these methods implicate a MCDM algorithm, or is applied to more than one application fields. There are decision making approaches that use ontologies, and also a few ontology-based MCDM methods. However, the majority of them are not dynamic. They are implemented to meet the specific needs of a single domain, while the only general ontology-based MCDM method captures the MCDM concepts and relationships into the ontology and rules and does not implement a MCDM algorithm. As far as it concerns the multifaceted methods, they comprise multiple levels of criteria, instead of clustering the criteria like in our method. According to literature, visual analytics and ontologies have been used in combination. However, the before mentioned methods do not implement a decision making algorithm, let alone a MCDM algorithm.

Chapter 3 . Methodology

3.1 Introduction

In this chapter, the MOBVR (Multidimensional Ontology Based Visual Ranking) framework is presented. The proposed approach copes with the ranking of entities with multidimensional character. To make a decision on multifaceted setting, decision makers need to understand the implicated data. Therefore, it is essential to handle the complexity of the multidimensional decision support process and to enable decision makers to acquire the needed context and background knowledge to make informed decisions. An effective way to reduce this complexity is by visualizing the related information and thus exploiting the increased human visual perceptual abilities, while the relationships and the correlations among the data are more efficiently portrayed and explored through the semantic web technologies that also facilitate the interoperability of both the data and the system.

The MOBVR framework incorporates visual analytics and semantic web technologies into multidimensional decision support to facilitate the decision making process and to make available the information required to conclude to a decision. It builds upon the MOBVR-ELECTRE III, the ontology-based ELECTRE III algorithm (presented in 3.3.4.4). Moreover, it proposes the LODification method, for the unification of heterogeneous data and the DATA alignment method, for the matching of the domain independent to the domain specific parts of the MOBVR ontology. As far as it concerns the presentation of the data, we propose Semantic Decision Rules (SDR) to determine over insolvabilities on the alternatives, Semantic Predefined Queries (SPQ) to provide further exploration of the dataset, while the visual analytics components (comparative alternatives ranking and entity's performance fingerprint) make possible the deeper understanding of the data.

3.2 Structure

This chapter is structured as follows: the methodology is presented, and then each layer of the framework is thoroughly described. Subsequently, the two case studies in which our methodology is applied are briefly discussed, followed by the summary and conclusions of this chapter.

3.3 Methodology

The dissertation proposes the Multidimensional Ontology Based Visual Ranking (MOBVR) framework as a way to solve ranking problems in cases that involve domains characterized by many profiles, multiple dimensions and numerous criteria. The methodology examines the benefits that are introduced from integrating visual analytics and semantic web technologies into the MCDM to provide the decision maker with an interactive and comprehensive system to deal with large amounts of intricate data.

More specifically, multidimensional ranking outputs are presented in a comprehensive, interactive manner via the comparative ranking of alternatives. To elaborate, comparative ranking displays the ranked order of the alternatives in the selected dimensions (i.e. the themes of the criteria) and portrayed by parallel coordinates. Moreover, the performance of a single alternative on the specified dimensions is portrayed by the entity's performance fingerprint, which is implemented with radar chart. Likewise, semantic web technologies enrich the process with dynamic features through the mapping of the domain specific ontology to the domain independent ontology. They also enable deeper understanding through the predefined semantic queries, which are predetermined SPARQL queries and solve incomparability issues that may happen into the decision making method with the semantic decision rules. The way, in which the particular components of the proposed decision making approach lead into informed decisions, will be explicated in the following paragraphs.

3.3.1 General definition of the approach

Multidimensional Ontology-Based Visual Ranking encompasses the common elements of multidimensional domains (elements of general nature) to cover the ranking problematic. In order to empower the method with the required and the desired capabilities, we introduce state-of-the art approaches for the processing, the management and the presentation of information. The methodology, which is designed for this problem, entails an ontology-based architecture for multidimensional decision support. Each component of the framework is structured based on semantic web principles, so as to promote domain independency and profound data exploration and management. In particular, the MCDM method relies on ontologies to execute all the data-related transactions and the visual analytics features of the framework are also ontology-based. As a direct consequence, the change of the ontology and the ontology-structure data suffice for applying the method to another domain, since the remaining components are affected by it.

Rankings provide a rank order of a set of alternatives based on defined criteria. However, the concern of the stakeholders exceeds the presentation of the outputs of the rankings. The ranking processes should fulfill specific requirements. These requirements include efficiency, transparency, personalization and easier comprehension by the decision makers and are addressed by implementing a visual, dynamic method based on an outranking algorithm for ranking problematic. To elaborate, efficiency is achieved by the implementation of multiple criteria ranking algorithms because of the multivariate character of the problem. Transparency is ensured by the use of ontologies, which facilitate data sharing, openness and interoperability, whereas personalization is realized by the modularity of the proposed method. To be more specific, the aspects of the application domain can be employed either autonomously or they can be combined in order to create representative ranking profiles for the selected domain. The use of visual analytics for the presentation of results of the ranking algorithm enable their easier comprehension by the decision maker by taking advantage of the human ability to process and comprehend larger amount of data when presented in visual form [97]. The main novelty of the proposed approach is the combination and integration of three scientific areas, namely ontologies, visual analytics and the outranking technique to provide a dynamic framework for the whole decision support process.

3.3.2 Significant variables

The most significant variables of the proposed methodology are the following: a) the multidimensional character of the entities to be ranked and b) the openness of the related data, since the whole approach depends on these characteristics. The multidimensionality of the entities to be ranked is a necessary and sufficient condition for the application of the multi-criteria decision support procedure, as will be further discussed in the description of the MOBVR competency check (3.3.4.1). The entities' multidimensional character is portrayed and preserved in the MOBVR framework. The methodology is built in such a way that it facilitates the multidimensional aspects of the rankings' subject, promoting its complex and multilevel nature. This ultimately enables the decision makers to obtain a more complete understanding of the problem at hand, due to the fact that the approach promotes the important aspects of the domain. The open philosophy of the data is required in order to make possible the LODification, publication and reuse of the information, which lead to the transparency and reproducibility of the rankings. It must be mentioned that in the case of sensitive and private data within the dataset, they should be excluded from the reusability stage of the proposed framework.

3.3.3 Instrumentation

The MOBVR approach is synthesized by the combination of the following components a) the MOBVR ELECTRE III, b) the visual analytics and c) the underlying ontology. The goal of our system is to identify the performance of each entity and to conclude which one performs better than others in the selected dimensions. In ranking problematic, all the actions in a specific set are rated from the best to the worst [9]. The ELECTRE methods that deal with ranking are ELECTRE II, ELECTRE III and ELECTRE IV. ELECTRE III method is considered an efficient approach for dealing with multiple criteria ranking. Even though this method gives precise and valid results that consider relative importance indices, the interactions between the user and the system could be further ameliorated.

Visual analytics are introduced in the decision support procedure for the presentation of the ordered alternatives and the enhancement of the process, in aspects of performance, time and effort, as well as user experience, as opposed to a non-visual-assisted ELECTRE III. Visual analytics were chosen over visualizations due to the large amount of information and the ability of visual analytics to handle datasets of such magnitude. The adoption of an ontology-based architecture for our system stems from the need i) to produce reproducible and transparent ranking results, ii) to make available the information in LOD format and iii) to facilitate the data through the whole sequence of the system, iv) to increase the adaptability of the system and v) the exploration of the dataset. Ontologies were selected instead of relational databases due to the interoperability that they bring to the data, the structure that they formulate, as well as their reasoning capabilities. Moreover, ontologies were considered over other semantic web structures (i.e. taxonomies, thesauri, etc.) because of the fact that ontologies offer stronger semantics, since they can also express axioms and restrictions, whereas the other variants cannot.

3.3.4 Procedure

The multidimensional rankings include many dimensions (or subdomains), these subdomains may reveal significant insights related to the performance of the alternatives, which may have impact on the formation of the choice of the decision maker. Given a multidimensional domain, the proposed framework can generate reproducible ranking outcomes. The MOBVR procedure is designed to host any multiple criteria decision making / aiding method, since all the characteristics and the peculiarities of them are captured in the MCDM-base ontology. It can also be specialized in order to accommodate any multidimensional domain, due to the fact that the details of the domain are depicted in the corresponding domain ontology.

Given a domain and a decision making algorithm, there is a sequence of steps in order for the MOBVR framework to be applied. The general methodology of the proposed framework is described in the Figure 13. The flowchart of the MOBVR framework is expressed in Business Process Model and Notation (BPMN) The basic steps of the process are the following: (1) Prior to the implementation of the methodology, the domain has to be examined by the MOBVR competency check, which is a set of requirements that should be met by the specified domain, (2) then the development of ontology takes place. (3) The values of the MOBVR- ELECTRE III are determined and (4) the data is aggregated to the system, (5) the data is handled in order to have a data format compliant to the system's architecture, (6) the multidimensional decision mechanism ranks the gathered and unified data, (7) then the information is presented interactively with data visualizations, visual analytics and textual data presentation, as well as semantic rules and queries, (8) while the data is available in reusable data format, so as to be utilized again in other systems and can also be published to LOD cloud. (9) The decision maker consults the system to gather the required information on the alternatives and (10) based on the suggestions of the MOBVR system can make a decision.

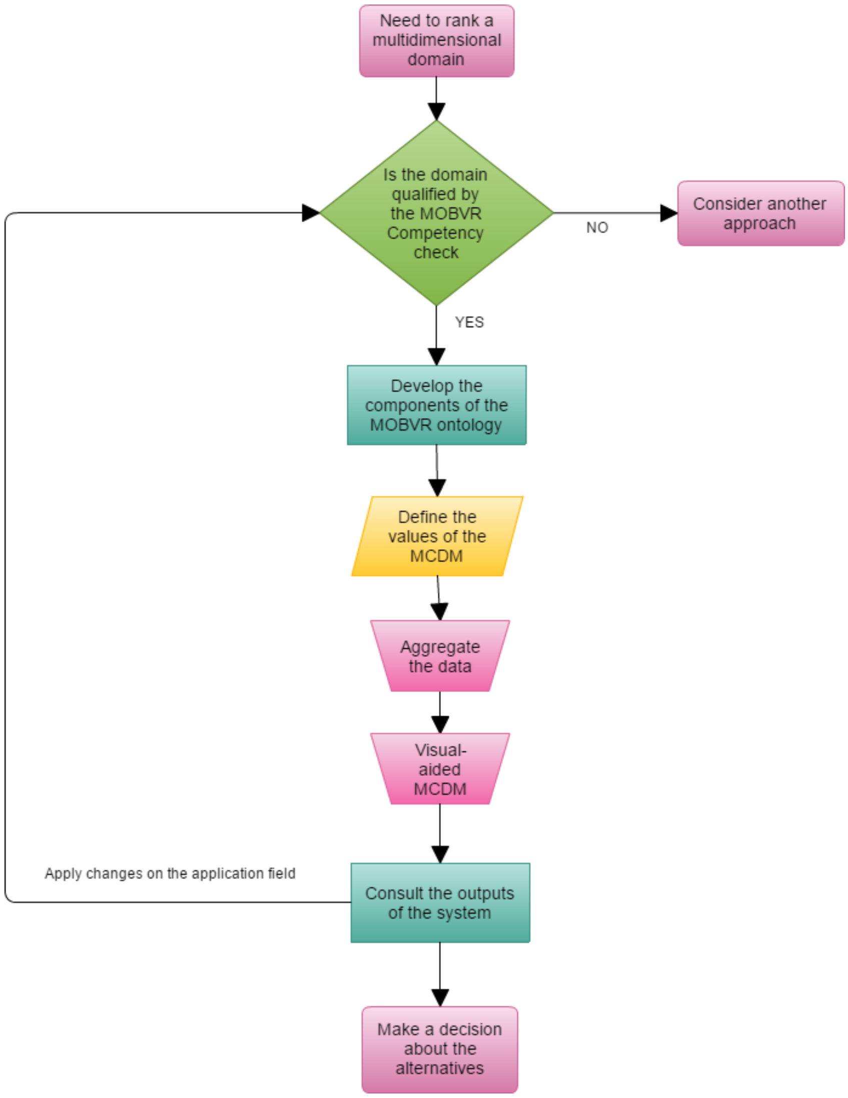


Figure 13 – Flowchart of ranking a multidimensional domain [293]

Based on the proposed methodology, the MOBVR system (Figure 14) has been developed, in which the intersection of techniques from different research areas is examined and implemented. The framework is built to support ranking and comprises the competency check, the data layer, the ontology layer, the dynamic MCDM layer, the interactive presentation layer, as well as the reusability layer. Each layer of the methodology will be further discussed at the subsequent subsections. The MOBVR framework initiates with the competency check (that will be introduced in 3.3.4.1 The MOBVR competency check) and the data layer (more details on the section 3.3.4.2 Data layer) in which the data is imported to the system from disparate sources and various formats. Subsequently, in the ontology layer, the input data is modified with the aid of the ontology to ontology-structured data (it will be described in 3.3.4.3 Ontology layer), then the dynamic multiple criteria decision making layer takes place, in which the ontology and the ontology-structured data are utilized in the selected multiple criteria decision support method (a detailed description is available at 3.3.4.4 dynamic multiple criteria decision making layer), the results of which are displayed via the interactive presentation layer (this will be discussed thoroughly in 3.3.4.5 Interactive presentation layer), which is composed visual analytics and semantic web technologies. The data, on which the rankings were based, and the rankings' results can be extracted in the reusability layer (more information about which is available in 3.3.4.6 Reusability layer).

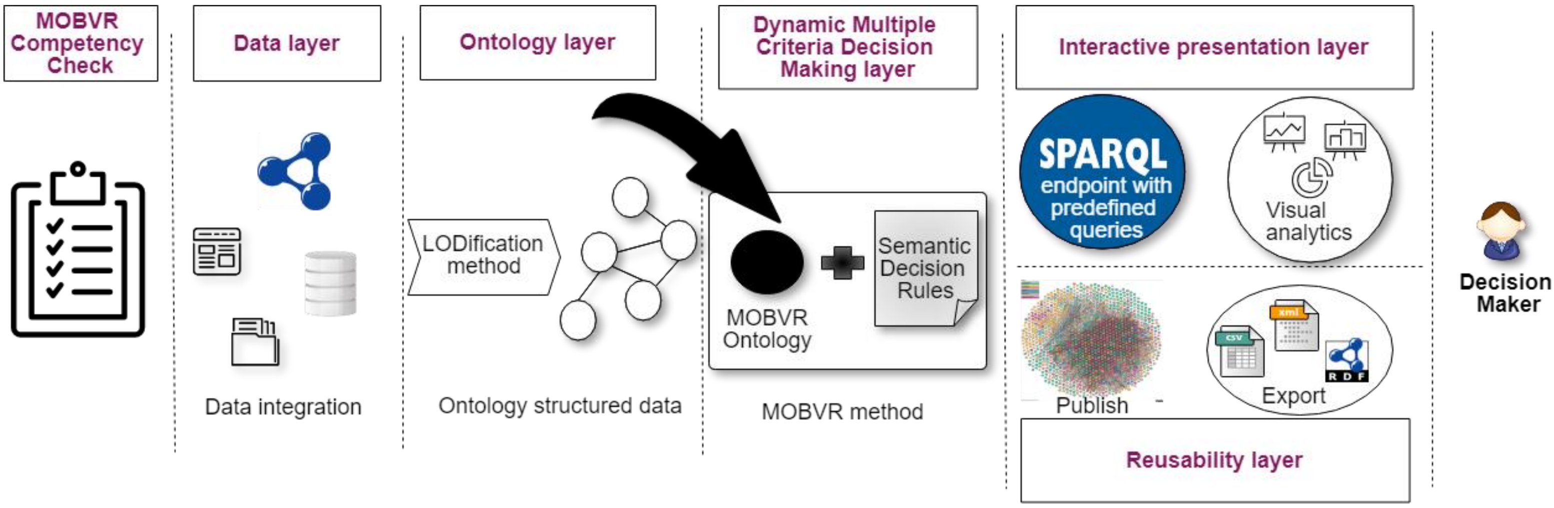


Figure 14 – The MOBVR architecture (adapted from [294])

3.3.4.1 The MOBVR competency check

The MOBVR competency check constitutes a set of prerequisites, which the application domain should suffice, in order to implement the MOBVR methodology to it. The obligation of each requirement in the competency check can be either mandatory or optional. The requirements along with their obligation are presented in Table 2.

Table 2 - MOBVR competency check and the obligation of the questions [292]

Competency check qualification questions	Obligation
Applicability of the MOBVR to the domain	
C.C.1: Is the domain multidimensional?	Mandatory
C.C.1a: Is the domain characterized by multiple criteria?	Mandatory
C.C.1b: Can those criteria be grouped into separate dimensions?	Mandatory
C.C.2: Is the ranking the intended use?	Mandatory
C.C.3: Are the values comparable?	Mandatory

C.C.3a:Performance	At least one	Optional
C.C.3b:Requirments		Optional
C.C.3c:Skills		Optional
C.C.4: Is the information open?		Mandatory
C.C.4a: Has the information a Creative Commons (CC) License?		Optional
Applicability of ELECTRE III to the domain		
C.C.5: Are there any preferred values or ranges of values for one or more criteria?		Mandatory
C.C.6: Is there a minimum difference in one or more criteria between the alternatives that is insignificant?		Mandatory
C.C.7: Is there any values in one or more criteria that is undesired?		Optional
Particularities of the domain		
C.C.8: How many dimensions are there in the selected domain?		Mandatory
C.C.9: Which dimensions (groups of criteria) are there in the selected domain?		Mandatory
C.C.10: How many criteria are there in each dimension?		Mandatory
C.C.:11: Which criteria are there in each dimension?		Mandatory
C.C.12: Define the importance of each criterion and dimension.		Mandatory
C.C.13: Does the approach include uncertain information?	At least one	Optional
C.C.14: Does the approach include quantitative criteria?		Optional
C.C.15: Does the approach include qualitative criteria?		Optional

These requirements correspond to qualification questions that are grouped in three categories. The first group of the qualification questions (Table 2, C.C.1-C.C.4a) ensures the existence of compulsory features in the selected domain and includes: the multidimensionality of the application domain, the large number of criteria, the openness of the information and the existence of comparable values, which can be numerical or otherwise, for instance performance indicators, requirements and skills. The second group of the qualification questions (Table 2, C.C.5-C.C.7) confirms the applicability of the selected multiple criteria decision support method, in our case the ELECTRE III, to the application domain and take account the preferred values or ranges of values of the criteria, the minimum difference between the values of the alternatives in a specific criterion that is considered insignificant or even the undesired values in some criteria. The last group of requirements (Table 2, C.C.8-C.C.15) involves important information for the application of the methodology to the selected domain: the number of dimensions of the domain and the number of the criteria of each dimension, the classification of the criteria to the respective dimensions, and the weights of the criteria and dimensions.

In case the application domain does not pass a stage of the competency check, then the check is dismissed, while the selected domain is characterized as ineligible for the framework. As a direct consequence, an alternative approach should be selected. The inspection of the domain by the MOBVR competency check is vital importance for the MOBVR approach, because it ensures i) its applicability to the selected application field and ii) conduct preliminary process of the domain by retrieving the required for the subsequent stages of the framework. As soon as the compatibility of the domain at hand with the MOBVR framework is confirmed, the data layer takes place.

3.3.4.2 Data layer

On the data layer, the data that is necessary for the evaluation of an entity is accumulated. In this phase, the domain specific data is aggregated to the system by the import procedures and can be derived by different data sources including websites, databases, which may be proprietary or not, or it can be directly imported by the web interface of the MOBVR Information System. The supported file formats of the aggregation modules are relational databases, or reusable formats, such as CSV (Comma-separated values), JSON files, Linked Data and Linked Open Data compliant files. During the data layer, data preprocessing occurs, which involves activities, such as data cleansing, data integration and data transformation. The user interface, apart from the data aggregation, allows for the management of the information, including viewing, editing and deleting information. ELECTRE requires the input of the preference, indifference and veto thresholds, as well as weights for each criterion and dimension. The large amount of criteria and dimensions may cause difficulties to the decision makers. So, presets of weights and thresholds are defined in order to cope with the multitude of the data required to be set by the decision maker.

3.3.4.3 Ontology layer

The MOBVR framework relies on the MOBVR ontology, which is a composite ontology and evolves through the MOBVR system. The ontology is composed by four independent, yet interacting, components, namely the MCDM-base ontology, the domain specific ontology, the ranking ontology and the MCDM-outputs ontology. The domain is the “instance” of the application domain and captures the information of the application field. The MCDM-base ontology portrays the terms related to the multiple criteria decision making component. It is a generic ontology, in terms of being independent from the application domain. To be more specific, it models the information needed from the MCDM algorithm including the dimensions, the criteria and the weights, while the ranking ontology contains information about the ranking profiles. The ranking profiles define the context of the ranking and can be general, dimension-centered, or composite, with the general ranking profile depicting all the dimensions of the ranking, the dimension-centered profile is specialized in only one dimension, while the composite profile implicate two or more dimensions. The MCDM outputs ontology is a general ontology that represents the products of the multiple criteria decision making / aiding method on the selected domain. The system initiates with the MCDM-base ontology and the MCDM-outputs ontology defined in accordance with the selected multiple criteria decision support algorithm (ELECTRE III), the ranking ontology express the character of the ranking profiles, whereas the domain specific ontology is directly linked with the subject of the ranking and thus they are created after the specification of the domain. However, the instances of the ontologies are created in a different order. The domain specific ontology is instantiated first; afterwards the instances of the ranking ontology are created. Then the instances of the MCDM-base ontology are generated and the MCDM outputs ontology is filled with contents last. To elaborate, the alignment between the terms of the domain independent ontologies and their actual values is executed by matching its concepts with the domain specific ontology, by the respective component of our system (DATA alignment method), while the MCDM-outputs ontology is instantiated by the execution of the MOBVR-ELECTRE III algorithm and are influenced by the values of the rest components of the MOBVR ontology.

In order to deal with the heterogeneity of the data introduced by the previous layer (data layer), data unification takes place. Thus, in the ontology layer, the data is structured with the aid of the domain specific ontology to Linked Open Data, so as to achieve unanimity over the data and to be able to process it in our system. This conversion is fulfilled by the LODification process and builds upon the concepts and the relationships of the ontology to modify the imported data to a single format that can be handled by the decision making procedure. The LODification method is composed by an alignment procedure, which maps the accumulated information (relational databases and other data formats) to the ontology and a converting module in which the actual LODification of the data is happening and keeps data available in semantic web format (in TDB format - Jena Semantic Web framework). The LODification method builds upon the domain ontology to convert the input data to LOD compliant format, so as to be utilized by the MOBVR system. This is achieved by exploiting the already existing associations on the data, as well as the relationships described in the ontology. This process results on data that can be easily reused, due to the ontology-based structure.

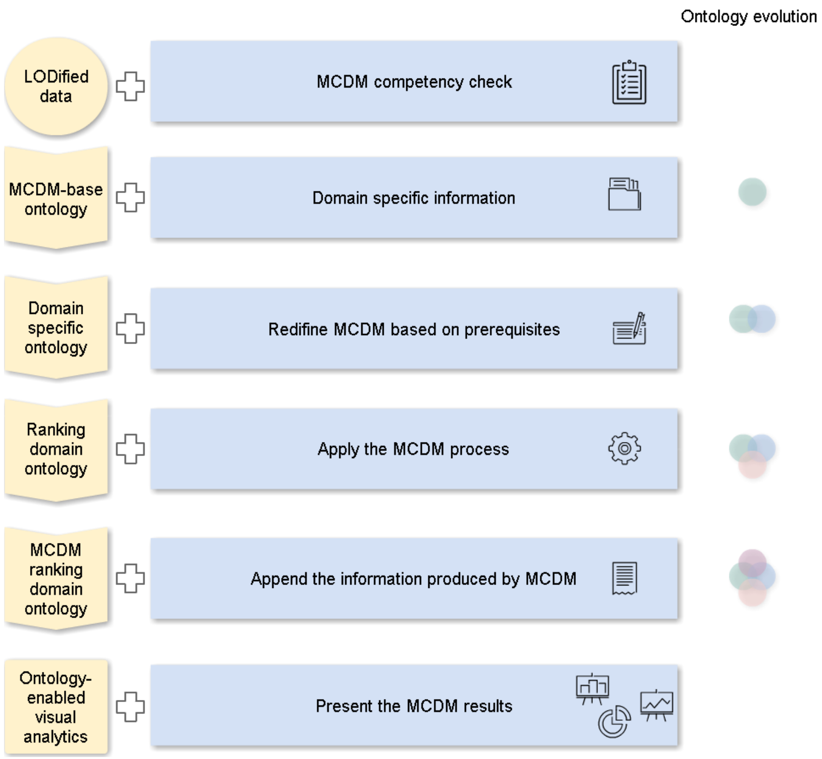


Figure 15 – The evolution of the ontology throughout the framework

The MOBVR ontology is crucial for the transparency, the reproducibility and the assurance of validity of the results of the proposed method, since it is the basis for the LODification method and the publishing of the ranking data as Linked Open Data. It enables the adaptation of the framework to a different domain; while the only prerequisite is the definition of two new ontologies, one focused on the domain and one focused on the ranking methodology. As mentioned before, the MOBVR ontology allows also the adaptation to a different MCDM method, by altering the MCDM-base and the MCDM-outputs ontology and capturing the characteristics of the selected MCDM method and the expected results respectively. As a direct consequence, due to the MOBVR ontology the framework becomes dynamic and adaptable to the needs and specifications of the decision maker. Figure 15 displays the way that the ontology evolves through the framework. At the final stage of the ontology layer, all the parts of the MOBVR ontology, except from the MCDM-outputs, are instantiated and in LOD format.

In this stage, apart from the LODification method, the alignment of the ontology components takes place. As mentioned before, the domain independent MOBVR ontologies are instantiated based on the alignment between the domain specific and the domain independent parts of the MOBVR ontology, which is implemented by the DATA (Decision Aiding Terms Alignment) alignment method (Figure 16). This component supports the system and the data interoperability and the dynamic character of our method.

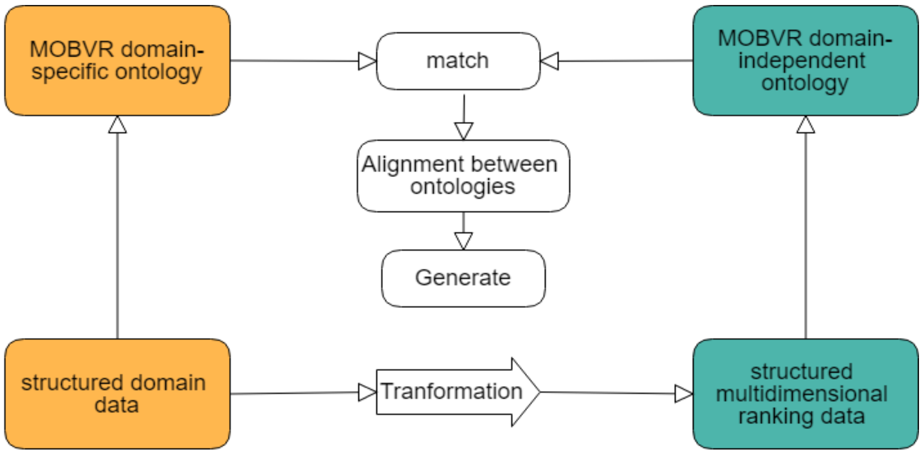


Figure 16 – DATA (Decision Aiding Terms Alignment) method

The ontologies to be aligned have not any similarities on names or descriptions, because they conceptualize different notions, they are not just different conceptualizations of the same entities. As a direct consequence, alignment techniques, such as string-based, or language-based cannot be employed. So, a hybrid method, namely the DATA method, using domain specific thesauri (exploiting the background knowledge) and a model-based technique (propositional satisfiability / Description Logic) has been developed and employed.

Table 3 – Example of values' assignment of domain to MCDM-base ontology [293]

MCDM base ontology	**Domain specific ontology**	**Instance/ value**
Dimension 2 (concept)	Research (concept)	-
Weight of dimension 2 (datatype property)	Weight of dimension research (datatype property)	30%
Criterion 1 (concept)	Amount of papers/academic (concept)	-
Weight of criterion 1 (datatype property)	Weight of dimension amount of papers per academic (datatype property)	15%
Alternatives (concept)	Faculty (concept)	Faculty 1
		Faculty 2

		Faculty 3
		Faculty 4
		Faculty 5

The thesauri contains information about the classes of the domain specific parts of the MOBVR ontology that correspond to the vital parts of the multi-criteria ranking method (such as the alternatives, the criteria, the dimensions, the profiles, etc.) and hence the domain independent MCDM-base ontology. The rest of the relationships are derived by the DATA alignment method, based on the given relationships and structure. An example of the alignment, for the academic domain, is illustrated in the following table (Table 3).

3.3.4.4 Dynamic multidimensional decision making layer

A multiple-criteria decision support methodology that covers a wide spectrum of problems, like the proposed methodology, should be easily implementable and personalizable in other individual cases (application domains). This implies that the methodology is independent of the context of the problem, thus generic, and that it is developed in such a way that it can be easily adapted to the domain requirements and the end-user needs, thus dynamic. Moreover, to respond to problems of great complexity, a multidimensional approach that considers multiple criteria has been adopted, characterized by weights, which specify the importance of each criterion grouped in dimensions and their corresponding weights. As far as it concerns the dimensions, they are not limited to provide grouping of the criteria. They also function as modules of the domain that may stand-alone or form combinations which results to profiles that respond to the nature of the domain.

During the decision making layer, the MOBVR ELECTRE III algorithm, determines the ranking results. The MOBVR ELECTRE III algorithm is built upon the ELECTRE III algorithm. The parameters of the multiple criteria decision aiding method are implemented as variables. Furthermore, the MOBVR-ELECTRE III has broadened the scope of the original ELECTRE III, by substituting the variables with ontology concepts and properties, because ontologies expedite the adaptation of the application field into the MCDM method. As a result, this approach makes possible the reuse of the same methodology with minor changes in any domain and also facilitates an effortless transition to another MCDM method.

Our MCDM method not only consumes information structured by an ontology like several other approaches [117, 119, 120], but also the whole MCDM process is ontology driven and it includes decision making rules into the ontology. Likewise, it does not rely only on reasoning mechanisms similar to the method presented by [109], but it also implements a concrete multi-criteria method, because the results of such a method are crucial for our approach, since it gives elaborate ranking results that cannot be achieved only by the use of an inference engine. The MOBVR framework is based on an intricate synergy among the decision support method and the ontology, leading to enhanced semantic structure and storing of the data, deeper understanding and exploration of the information, as well as resolution of the possible problems and thorough consultation to decision makers. MOBVR-ELECTRE III takes advantage of the benefits of multiple criteria decision aiding and semantic web, without being susceptible to the same limitations. The MOBVR-ELECTRE III method is implemented, computing the criteria of each dimension (lines 5-22) - algorithm 1 (table 4) - and then each dimension and the total ranking order are calculated based on the results of its individual components (lines 4-39). The final outcome of the process is the multi-faceted ranking order of the alternatives, consisted of a separate ranking order for each dimension, as well as the overall ranking order and preserves the cases of incomparability and indifference within the ranking order.

Table 4 - The MOBVR-ELECTRE III and MOBVR resolution method [294]

<u>Algorithm 1. MOBVR-ELECTRE III method</u>	<u>Algorithm 2. MOBVR-ELECTRE III Resolution method</u>
1: function MOBVR-ELECTRE III (Ontology MOBVR) 2: Cr <- list of $g_j \in G$ 3: Dim <- list of $d_j \in D$ 4: for all dim ∈ Dim do 5: for all cr ∈ Cr do 6: Calculate Concordance Index 7: Calculate Discordance Index 8: Calculate Credibility Index 9: end for 10: Calculate overall concordance index for 1 dimension 11: Determining descending distillation 12: if there is Incomparability or Indifference	1: function Resolution 2: if (aIb) or (aRb) 3: Call the SDR 4: While a resolution is not achieved 5: Subtract the criterion that hinder resolution 6: Call the SDR 7: Determine Resolution 8: end if 9: end

```
            Call the Resolution method
        end if
        Determining ascending distillation
        if there is Incomparability or Indifference
            Call the Resolution method
        end if
        Determining final ranking
        if there is Incomparability or Indifference
            Call the Resolution method
        end if
        Calculate Dimension's Concordance Index
        Calculate Dimension's Discordance Index
        Calculate Dimension's Credibility Index
    end for
    Calculate overall concordance index for all the dimensions
    Determining descending distillation
    if there is Incomparability or Indifference
        Call the Resolution method
    end if
    Determining ascending distillation
    if there is Incomparability or Indifference
        Call the Resolution method
    end if
    Determining final ranking
    if there is Incomparability or Indifference
        Call the Resolution method
    end if
    Append MCDM outputs to the MPBVR ontology
    Return MCDM outputs
end
```

To elaborate, the cases of incomparability and indifference between two alternatives are of vital importance for the ELECTRE approaches and therefore they should be depicted in the rankings. Incomparability expresses the absence of evidence that an alternative surpass the other, while indifference denotes that the difference among two alternatives is not adequate to propose a solution based on the preference of the decision maker. However, in some cases it is essential to propose one alternative over the other. The semantic decision rules (SDRs) regulate the decision making in occasions where the algorithm is inconclusive, for instance in the before mentioned cases (incomparability and indifference), by suggesting a solution to the decision maker for these cases. SDRs are SWRL rules that supplement the MOBVR-ELECTRE III and its outputs. They are created along with the ontology and are utilized by the ontology-based MCDM algorithm. The MOBVR-ELECTRE III method takes incomparability and indifference into account during the presentation of the ranking order. Thus, the intention of the SDR mechanism is not to override the utilized algorithm, but rather to propose a preference among alternatives when it seems necessary by the decision makers, by redirecting the decision maker to the inference engine in order to make a suggestion. Therefore, even though a complete ranking order is not always desirable, nor required, complete ranking orders of subgroups of the set of the alternatives (one per each position of incomparability or indifference at each dimension) are suggested to the decision maker. This provides the decision maker with as much information as possible and a broader view of the possible solutions. The semantic decision rules occur after the decision making process and prior to the presentation of the ranking outcomes. To be more precise a set of SDR is prepared and available in the background, if there is lack of preference among two or more alternatives and is composed by a set of rules related to the criteria / dimensions.

Allow us to assume that two or more alternatives raise incomparability or indifference. The aforementioned process, which is also displayed in table 4 – algorithm 2, is structured as follows:

i. The set of semantic decision rules are called for the ranking position, in which there is insolvability.
ii. While insolvability continues to exist the semantic decision rules that keep on hindering the resolution are subtracted.
iii. A preferred ranking solution is proposed to the decision maker.

As mentioned before, building on the rest components of the MOBVR ontology and their contents, the instantiation of the last part of the MOBVR ontology, the MCDM-outputs, takes place through the MOBVR-ELECTRE III algorithm. To sum up, the dynamic multidimensional decision making layer results to a ranked order of the alternatives based on the MOBVR-ELECTRE III algorithm and the complementary semantic resolution rules. The results of this layer are portrayed and appended to the ontology structured data and they are ready to be processed by the subsequent layers, the presentation and the reuse.

The ontology-based method has several differences from the original ELECTRE III, while it holds a number of the same characteristics. First and foremost, the ontology-based ELECTRE III builds its rankings on dimensions and criteria, while the original ELECTRE III ranks the alternatives only on criteria. The dimensions can be referred as individual profiles – facets – of an entity that are vital for its satisfactory level of functioning. They categorize the criteria into clusters based on their similarity. The activities that take place into an organization, for instance, can be grouped in the following categories, or dimensions, financial, management, marketing, trading, corporate social responsibility, etc., while the criteria of the financial dimension can be the following: incomes, expenses, payments, taxes, etc., and so on.

The dimensions establish an extra level of complexity in the computation of the ranking and they also take into account the preference of the decision maker in the categories in which the criteria fall into. This is essential in the multivariate rankings, because each aspect of the object to be ranked contributes differently to the final ranking for each decision maker. In the original ELECTRE III, only the criteria define the final ranking, whereas each criterion contributes with a different weight to the rankings. Similar to the way that criteria are contributing to the final ranking in the original ELECTRE III method, the dimensions and the corresponding criteria in the MOBVR ELECTRE III method are characterized by weights that imply their significance in the ranking problem. However, there are not any dimensions in the ELECTRE III. The difference between the two methods lies in the utilization of additional indicators for the ranking. The added level of computation expresses the multi-faceted character of the targeted domains and allows for an accurate and realistic ranking.

Since the application domain consists of multiple aims, this should be mirrored in the respective rankings. Compared to the rankings that are based on the overall performance, multi-profile rankings, like MOBVR multidimensional ranking, cover a wider spectrum of the activities of an object. It preserves the diversity of an objects characteristics and objectives. It also enables the overview of the performance of an entity on the individual profiles in which its activities are categorized. Its performance on each profile may vary and can also deviate from the overall profile. For instance, the individual profile of corporate social responsibility takes into consideration only the criteria that belong to this dimension. So if a decision maker needs to assess the organization's corporate social responsibility, he/she should be able to access and evaluate only this dimension and its criteria.

The classic ELECTRE III utilizes variables, whereas the proposed ELECTRE III involves ontology and consequently its components, such as concepts, properties, relationships, rules and queries. The MOBVR ELECTRE III is designed to host ontology-structured information, which means that it is built upon the aforementioned principles of ontologies. As a result, the MOBVR ELECTRE III considers as input data in semantic web compliant format. The ontology-based ELECTRE III is flexible, dynamic, interoperable and transparent. Moreover, it is a part of a system and so it interacts with the rest components of that system, which are also ontology-based, whereas the original ELECTRE III is an application that does not act as a part of a system and where the user defines all the inputs of the system. Furthermore, the MOBVR ELECTRE III appends the outputs of the process along with the rest data making the ranking reproducible and able to be validated. The input of ELECTRE III is gotten from the user input in the values of the fields, whereas in our ELECTRE III the input is the LODified data. The ontology-based ELECTRE III takes as input the ontology-structured data of the MOBVR system. In fact, the input of the data in the MOBVR ELECTRE III is achieved with alignment of the parameters of ELECTRE III with the domain specific information. To be more specific, the input of the data of our method is in LOD format. This enables the application of our method in any LOD dataset, the availability of which is high. In the original ELECTRE III, the user should insert the values of the ELECTRE III required fields, which are the variables of the system. However, in case of the vast amount of data this process would become tedious and time consuming. As a result, the MOBVR ELECTRE III is far more scalable, fast, effortless and adjustable. The output of the ELECTRE III can be reused by the application, while the output of the MOBVR ELECTRE III can be reused by any Semantic Web application.

In our ELECTRE III the decision maker can access the ranking information about the dimensions and the criteria along with the information about the final ranking, while in the original ELECTRE III the user can access only the information about the final ranking. As far as it concerns the visualizations of the data, ELECTRE III provides basic visual representations, in contrast to MOBVR ELECTRE III that employs visual analytics. Our ELECTRE III method allows the deeper exploration of the related dataset with additional reasoning mechanism, while classic ELECTRE III does not provide such a mechanism. Moreover, the MOBVR ELECTRE III offers a resolution mechanism on the cases of indifference and incomparability, while the original ELECTRE III does not.

3.3.4.5 Interactive presentation layer

The interactive presentation layer relies on the dynamic decision layer and presents the data derived by that layer. The interactive presentation layer is realized by the MOBVR information system, which comprises the web interface, the visual analytics and the SPQ.

Since the problem of multidimensional rankings is multi-faceted and endows complex relations on the data, there is a profusion of information that may be difficult to be perceived and understood by the decision maker. Furthermore, the multiple criteria decision support process itself has high complexity. This complexity is also preserved in the rankings results and in some cases the amount of alternatives to be displayed is also vast. Nevertheless, the decision maker must make decisions without uncertainty. Consequently, the complexity that defines the multidimensional rankings, the ranking process and the related results should be diminished so as to ease the decision making process. When perplexed information is presented using visual analytics techniques, then it is better processed by the decision maker [97]. As a direct consequence, in the interactive presentation layer, the representation of the information relies on visual analytics, which focus on the information that is critical for the rankings and contribute to the final decision of the user. Moreover, the interactions facilitate a more profound comprehension of data by the users [266] and also offer insights that would be overlooked [207], interactive techniques (including filtering, brushing, zooming and details on demand) have been applied in the visual analytics employed by the MOBVR framework.

In the MOBVR system the alternatives comparative ranking and the unit's performance fingerprint are implemented, with the former being the visual representation of the results of the ranking for all the alternatives and for all the involved dimensions, while the latter focuses on the performance against the criteria of a single dimension or a profile for an alternative. In multidimensional rankings, the performance of an alternative at a dimension contributes to its overall performance. The performance of the alternatives in the individual dimensions may also affect the decision maker into forming his/her decision. Thus, it is essential to show the ranking results at each distinct dimension, in order to provide a more detailed consideration of the given problem and its solution.

The alternative's comparative ranking is performed with the assistance of parallel coordinates. PCP (Parallel Coordinates Plots) is a visualization technique that is capable of representing numerous alternatives and portraying their order in all the selected dimensions. In our case, it is accompanied with an interactive table, which presesnts the alternatives and their ranking position. Statistical coloring has been applied in a certain dimension and based on the value of each alternative in this axis (dimension) they are assigned with a color that follows them on the rest axes (e.g. dimensions). Therefore, the decision maker can effortlessly identify the overall performance of an alternative and recognize which alternatives have similar performances. Moreover, hovering over an alternative's name on the table, the corresponding line in the PCP is highlighted (displayed in a darker color) than the others. In this way, the decision maker can inspect the overall performance of each alternative in correlation with the rest alternatives that still appear in the visual representation, in lighter colors. Apart from PCP, pixel-oriented methods have also been taken into account. In pixel-oriented methods, the number of records that can be displayed is dictated by the size of the display area, so it confines the method's scalability. The interactions among the variables cannot be revealed, since each pixel represents a single variable. Hence, the PCP visual representation has been selected since it facilitates the discovery of patterns and dependencies on the data and it also allows the users to identify the whole picture. In case two alternatives are indifferent or incomparable in a dimension, they are ranked in the same position in that dimension. These cases can be further examined with the SDRs, which are embedded in the ontology and presented also with the PCP visual component. In the PCP of semantic decision rules, only the alternatives that raise indifference or incomparability are displayed, following the resolution method (presented in Table 4 – algorithm 2).

The entity's performance fingerprint is implemented with the radar chart visualization. The performance fingerprint of an entity allows the DM to inspect the status of a selected dimension, and focuses on the performance of its individual indicators. Aside from radar chart, bar graphs were taken into account, which display discrete, numerical comparisons through diverse categories. Nevertheless, in this case, the goal is to present the performance and not to compare the variables within a profile. Hence, the radar chart visualization was preferred, since it is ideal for performance presentation. The decision maker by choosing a specific dimension or profile can inspect the academic unit fingerprint consisting of the individual elements of the selected dimension or profile. As a direct consequence the performance in each aspect of the entity's character can be easily observed.

The MOBVR approach was built according to the visual analytics mantra *"Analyse First, Show the Important, Zoom, Filter and Analyse Further, Details on Demand"* [211]. The MOBVR approach adopts the visual analytics mantra, which is embedded in all its stages. MOBVR offers analysis of the dataset, as well as overview of its significant facets, while it also provides several interactions with the data, such as zooming, filtering and further exploration, and ways to explore the details of the vast datasets. As mentioned before, in the MOBVR framework, the information is visualized either with parallel coordinates, or radar chart. The parallel coordinates presents the results of the multidimensional profile, while radar chart offers a way to display the outcomes of the single dimensional and composites profiles. In the following section, we will inspect how the MOBVR approach reciprocates to the visual analytics mantra.

Analyse first & show the important: The information that is presented in the parallel coordinates plot has undergone analysis by the MOBVR algorithm. To be more precise, PCP displays the outputs of the algorithm (the ranked order of the alternatives), partitioned in dimensions. The radar chart involves the analysis and the presentation of the performance first on the general profile (consisted of all the discrete parts of the domain) and then the individual significant dimensions and profiles (comprised grouped criteria) of a selected alternative.

Zoom & filter: Statistical coloring has been applied to the alternatives in the parallel coordinates plot (the alternatives comparative ranking), denoting their status in a selected dimension and accompanies the other dimensions. Therefore, the decision maker can focus on a specific alternative. Another interaction available in PCP is the brushing of information, in which the decision maker can select a fragment of the values in the desired dimensions. The brushing of the outputs results to the presentation of a subset of the dataset that comply with the choices of the decision maker. So, decision makers are capable of filtering the alternatives based on the values that interest them. Decision makers are also able to change the order of the dimensions (columns) of PCP. As far as it concerns the radar chart (the entity's performance fingerprint), the decision maker apart from the general performance fingerprint of the entity, can also browse a more focused version of the performance fingerprint by selecting a specific dimension or profile.

Analyze Further & details on demand: PCP allows the further analysis of the ranking results in cases of indifference and incomparability by proposing and presenting resolutions to aid the decision maker conclude to his final decision. RC enables the examination of the performance of an alternative, as a whole and separately in each dimension/profile.

The characteristics of the MOBVR approach alleviate the information overload problem pinpointed in [19], by i) showing relevant data to the current task with the profiles, ii) by ensuring that the information is processed properly with the aid of the semantic web technologies and they are also displayed in an appropriate manner with visual analytics. A dataset of large magnitude complicates the discovery of significant information by the implicated decision makers. Semantic decision making enables the deeper exploration of the data, based on the semantic relationships. The decision making is further facilitated by the SPARQL endpoint enriched with predefined queries, which assist the investigation of the related data and support the informed decision making. The predefined queries are designed to ask meaningful questions related to the dimensions and the criteria of the MCDM ranking that would help the decision maker to conclude to an alternative.

The Semantic Predefined Queries (SPQs) are a set of semantic web based queries that are designed to distinguish the meaningful relations within the information. A SPQ queries the dataset by employing the relationships among the criteria and the dimensions, relying on the semantic web structure of the dataset and considering the declared significance (i.e. weights) of the criteria and the dimensions. The SPQ endpoint facilitates both novice and advanced end-users of the system, disclosing aspects of the information that otherwise would not be visible and the exploration of which would require a certain level of expertise. These queries retrieve the concepts that meet the given criteria. The decision maker can select a SPQ and then inspects the list of options that are consistent with the requirements.

3.3.4.5.1 The performance profiles

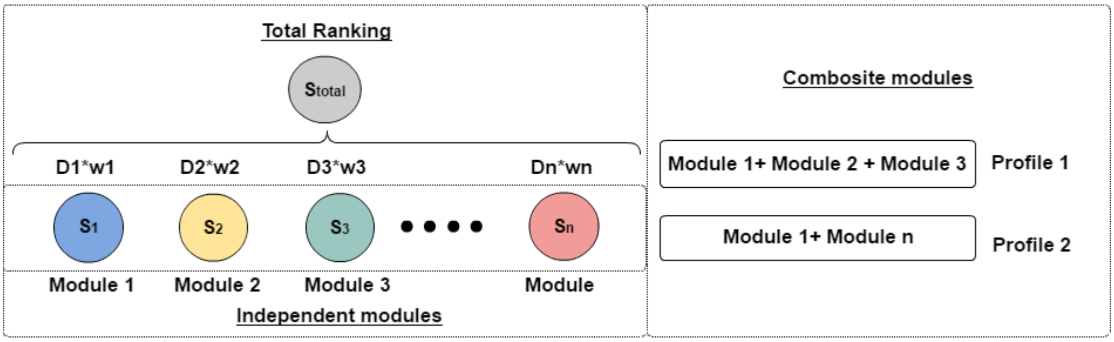


Figure 17 – Performance profiles

The performance profiles offer different perspectives of the same information, allowing decision makers to focus on the various facets of the domain. According to the different requirements and needs, a different performance profile is selected, ranging from uni-dimensional, to composite and multidimensional profiles.

Uni-dimensional profile: A uni-dimensional profile can be applied to a single dimension of the selected domain and reflects all the elements of that dimension. The relationship between a dimension and a profile of this kind is defined as:

$$P_U = \sum_{Cr_{in}}^{Cr_{i1}} Cr_{ij} w_{ij} \, , Cr_{ij} \in D_i,$$

where P_U is the profile that corresponds to one specific dimension, $\sum_{Cr_{in}}^{Cr_{i1}} Cr_{ij}$ are all the criteria of the selected dimension and D_i is the dimension.

The single dimension profile can be applied to one or more alternatives at once, to performances of a single alternative during different time periods, or even to the different dimensions of a single alternative. These profiles zoom into aspects of the character of an entity that are important in performing several tasks and in assisting several stakeholders. Each uni-dimensional profile is composed of the individual criteria (or groups of criteria) of the selected dimension and their weights. The outcomes of a single dimension profile (also called dimension) of an entity can be portrayed by the entity's performance fingerprint that is utilized to determine the suitability of the alternative to perform a specific task.

Composite profile: A composite profile comprises of two or more dimensions. A composite profile inherits the whole set of criteria and weights from its constituents dimensions. The following equation defines the association between the composite profile and the dimensions:

$$P_{Composite} = \begin{cases} P_n + P_m, \; for \text{ 2 dimensions } D_n \text{and } D_m \\ P_n + \cdots + P_m, for \text{ more than two dimensions } D_n, .., D_m \\ \left(\sum_{D_n}^{D_1} P_U\right), \text{for the whole set of dimensions} \end{cases},$$

where P_n is the uni-dimensional profile of the nth dimension, P_m is the unidimensional profile of the mth dimension, $\sum_{D_n}^{D_1} P_U$ is the summation of the profiles that compose the composite profile, P_U is the uni-dimensional profile of dimension D_1 to D_n.

Like the single dimension profile, the composite profile (or profile) focuses on the characteristics of an entity that are essential for completing several tasks and/or in supporting certain stakeholders. These profiles can also be implemented in one or more alternatives and for a single time period or for discrete time periods and can be depicted by the entity's performance fingerprint.

Multidimensional profile: A multidimensional profile is consisted of all the existing dimensions of a domain and presents the performances of all the alternatives. The relationship between the profile and the dimensions is identified as follows:

$$P_M \equiv \text{ function MOBVR} - \text{ELECTRE III (Ontology MOBVR)},$$

where P_M is the profile that is composed from all the dimensions and is given by the function MOBVR-ELECTRE III (Ontology MOBVR), which is defined in the Table 4 in section 3.3.4.4.

The multidimensional profile allows the overview of the performance of the alternatives in all the subdomains (dimensions) of a domain. Hence, it supports the visual representation of the overall rankings and is depicted with the comparative ranking of the alternatives. The multidimensional profile can be implemented for a single time period or during different time periods.

3.3.4.6 Reusability layer

The reusability layer entails all the necessary means for extracting the ranking information and results from the system in order to reuse it elsewhere. This layer implicates the export options of the data in several formats, as well as the publishing options in Linked Open Data. The goal of this layer is to make available the data gathered and generated by this approach for reuse and redistribution. Being able to retrieve data on which the rankings are based, reproduce the ranking results and have the original ranking results available for collation are of vital importance for the rankings. Since the whole information can be accessed and examined by the interested parties, the rankings are considered reproducible and transparent.

3.4 Limitations and delimitation

Since the method is applicable to digital information, the study is limited to those data that are available, or converted in such a format. Furthermore, dealing with open data is a delimitation that we have imposed in order to preserve the transparency of the rankings, in order to be able to achieve the same results again and ensure their reliability.

3.5 Case studies and cross-case analysis

Our framework is applied in two application fields in order to examine its validity and its transferability into other domains. The selected application domains are the academia and the world development domain. A cross case analysis has been conducted to reveal similarities across the case studies, to create models and disclose new aspects of the framework [285]. The case studies will be thoroughly described in section 4.6, while the cross-case analysis will be presented in section 4.8.

3.6 Summary and conclusion

The methodology presented in this chapter involves the exploration of the synergy among visual analytics, semantic web and multiple criteria decision support to facilitate insightful and informed decisions into multifaceted domains. Taking into account that all the components of the framework depend only on the ontology, the proposed framework can be employed in any context, in which there is the need for ranking deductions on complex and multidimensional data. During this chapter, the sequence of the steps of the methodology was introduced, along with the prerequisites for implementing the framework in the domain. The involved components of the framework and how each component affects the others were also examined.

Chapter 4 . Design and implementation

4.1 Introduction

This chapter provides thorough description of the design and the implementation of the prototype system according to the developed methodology. It exhibits the application of the methodology in two application fields to showcase the process, its results and its benefits. The development of the application is separated in the generic and the domain-specific components. The implementation to the selected application fields, which are the academia and the world development, is examined in the respective case studies.

4.2 Structure

The fourth chapter is structured as follows: the first section corresponds to the introduction. The second section outlines the structure of this chapter, while in the third and the fourth section, respectively, the key technologies and tools, as well as the key flows are explicated. The MOBVR system and its components are described in the fifth section. In the sixth section of the fourth chapter, the generic aspects of the MOBVR system are described, whereas in the seventh section, the case studies are thoroughly described, followed by a statistical analysis of the contents of the knowledge bases. In section nine a cross-case analysis is presented, providing the similarities, the differences and the patterns across the cases. Finally, the summary and conclusion section is provided.

4.3 Key technologies and tools

The system incorporates a number of technologies and tools to tackle with the problem of multidimensional ranking. Multidimensional rankings are applied in domains, the evaluation of which requires the processing of large amount of information. The key technologies and tools that are utilized in the proposed system can be classified into the following categories: i) visual analytics, ii) semantic web, iii) web programming, iv) decision support and especially multiple criteria decision making, as well as v) ranking techniques.

As far as it concerns the visual analytics methods and tools, the following are used: web visualization tools, such as visual-focused JavaScript libraries and especially the D3.js library, which provides a wide spectrum of visualization prototypes. Visual analytics techniques, such as statistical coloring, brushing, filtering and other interactions are infused into the visualizations. The semantic web technologies and tools that are utilized in the MOBVR system correspond to frameworks such as Jena, ontology design tools like Protégé, with which the ontology is created, SWRL reasoner and SPARQL endpoint to query the dataset. The web programming technologies employed by the MOBVR approach involve Java, HTML, CSS and JavaScript. The DSS components are designed and implemented in Java and influenced by the ELECTRE III MCDM approach. It must be mentioned that the original ELECTRE III application has been employed during the testing stage to verify the results of its visual counterpart (the MOBVR ELECTRE III). Apart of the above mentioned technologies and tools, rankings also imply the design of a methodological approach that leads to the resolution of a given problem. The combination of these key components leads to the MOBVR system, the creation of which demands multidisciplinary research on visual analytics, semantic web and multiple criteria decision making. The involved research disciplines are seamlessly combined into the proposed methodology, as shown in Chapter 3 – Methodology.

4.3.1 Key flows

The proposed methodology can be applied in a wide spectrum of problems and contains a generalized part and a domain specific one. The initial actions that should be followed for the design and implementation of the generic approach are the following:

- Implementation of the Web interface
- Design and implementation of a general ranking method
- Planning and building the Semantic Web background
- Development of the MCDM method
- Visual analytics approach

The before mentioned modules have been implemented during the initial implementation phase and are used without any change in all the application domains. However, in order to apply the proposed methodology to a certain domain, complementary, domain-specific, actions should be taken. So, the redesign of this approach in order to encompass the information of the selected application field involves the subsequent domain-specific actions:

- Conceptualization of the domain
- Specification of the ranking model for the domain
- Identification of the ranking profiles of the domain
- Redesign and implementation of the Semantic Web components.

A faster and more efficient adoption of the methodology to another domain is achieved with the generic components of the approach, while the domain specific components ensure the adaptability of the approach to the specific characteristics of the domain.

4.4 The MOBVR prototype

As mentioned before, the MOBVR (Multidimensional Ontology-Based Visual-aided Ranking) framework is applied to i) the multidimensional institutional ranking and to ii) the world development progress ranking. The data format that is used to showcase the prototype system is linked open data for both domains. In the following section these concepts will be analyzed thoroughly.

4.5 Generic aspects of the MOBVR system

4.5.1 Web interface

The web interface constitutes the interaction point between the MOBVR system and the decision makers. It allows decision makers to explore the initial data on which the rankings are based, in addition to the ranking results. The web interface of the MOBVR system can be seen as a reporting solution for the performance of the specified entities. It provides a unified way to perform rankings and to retrieve all the required information concerning the ranking objects in an easy, unambiguous and straightforward manner. The majority of the web interface is built during the implementation phase of the generic aspects of the system and is populated during the application of the methodology to the domain. To be more specific, it provides a prototype that can be specialized, creating MOBVR instances to meet the needs of a domain. The web interface comprises the textual web profiles of the ranking alternatives and other important concepts, the visual analytics components and provides access to the SPARQL endpoint. The web interface, besides presenting the rankings and ensuring that ranking information is broadly and openly available to the involved stakeholders, serves also as an information management system with profiling and discovery capabilities. The interested parties can access the contents of the web interface to support a variety of tasks that depend on the nature of the domain.

4.5.2 General ranking method

The profiles are distinguished into three categories, the multidimensional, the composite and the uni-dimensional (the profiles were thoroughly described in section 3.3.4.5.1). The former corresponds to the results of the application of the selected multiple criteria decision support method to the data (so it depends on the application of the method to the domain), providing the ranked order of the alternatives, while the latter two offer additional information about each alternative that contribute to the formation of the final decision, revealing details about alternatives and their performance that otherwise would be unnoticed (they depend solely in the domain and the nature of the domain). These categories of profiles constitute a standardized way to capture and display the facets that compose a domain. The profiles provide a general model that can be specialized for each application domain.

4.5.3 Semantic Web components

The generic semantic web components of the methodology include the parts of the ontology that describe the concepts of our approach that are not domain-specific, including the multi-criteria decision support method (i.e. the inputs, the outputs and the process itself) and ranking-related information. To elaborate, the generic ontology components are the following the MCDM-base ontology, which includes information about the process and its inputs, the MCDM-outputs ontology that depicts the results of the process, whereas the ranking ontology captures the possible ranking profiles. Given a multiple criteria decision making method, these parts of the ontology are designed once and then reused at any application domain. The instantiation of the MCDM-base and the ranking ontology ontologies is realized with the assistance of an ontology-matching method between the domain specific ontology and the generic ontologies, while the MCDM-outputs ontology is populated after the execution of the MOBVR algorithm on the domain data.

Apart from the ontology that facilitates the interoperability of the MOBVR method, SWRL rules are designed based on the generic components of the MOBVR ontology and propose a solution in incomparability and indifference cases. Since the SWRL rules are based only on the generic parts of the ontology, this constituent does not need reconfiguration when the methodology is applied in a domain. The rules are embedded in a visual analytics component, namely the comparative ranking of the alternatives, so as to be easier conceivable by the decision maker.

4.5.3.1.1 Ontology design & implementation

In this section the methodology followed for the development of the general aspects of the ontology is thoroughly described. The MOBVR domain independent ontologies are the MCDM-base [286] and the MCDM-outputs [287] ontology.

Step 1: Determine the domain and the scope of the ontology

Table 5 – MOBVR ontology requirements specification

Purpose
The purpose of building the MOBVR ontology is to provide a knowledge model of the multidimensional ranking. It is a composite ontology, which involves the MCDM-base ontology, which depicts the required input information for the rankings, the MCDM outputs ontology, which captures the outputs of the rankings and the ranking ontology, which portrays the ranking profiles. The MOBVR (Multidimensional Ontology-Based Visual Ranking) ontology will be used as a basis for the facilitation of the multidimensional ranking.
Scope
The domain of our ontology is the multidimensional ranking problematic.
Implementation Language
The ontology has been implemented in OWL 2.
Intended End Users

The intended end users are decision makers.
Intended Uses
The main indented use of the ontology is the facilitation of multidimensional ranking.
Ontology requirements
i) Non-functional requirements
The non-functional requirements of the MOBVR ontology are the following: The ontology should support English language. The terminology that is used in the ontology must be consistent to the terms used in ranking.
ii) Functional requirements
An excerpt of the competency questions for MOBVR ontology: 1. How many dimensions can be used to group the criteria? 2. Show me all the alternatives. 3. Find the ranking order of the alternatives. 4. What are the most important components of the ranking? 5. What kinds of profiles can result from the ranking?

Competency questions

The competency questions are used to extract the terminology, the concepts, of the ontology and its frequency. The competency questions that are created in the context of developing the MOBVR ontology are thoroughly described in this section.

1. How many dimensions can be used to group the criteria?
2. Show me all the alternatives.
3. Find the ranking order of the alternatives.
4. What are the most important components of the ranking?
5. What kinds of profiles can result from the ranking?
6. Find all the criteria.
7. What is the significance of each criterion?
8. What information is required as input for the rakings?
9. What information is output by the rankings?
10. What are the components of the ranking?

Step 2: Consider reusing existing ontologies

No existing ontologies are reused for the development of the general aspects of the MOBVR ontology.

Step 3: Enumerate important terms in the ontology

The MOBVR ontology describes the whole information that is required to perform and evaluate multidimensional rankings. Hence, it includes information about the inputs, the outputs of the ranking, as well as the terms that are required for the implementation of the ranking process and the description of the ranking profiles. During the ontology design process, we extract the terminology and its frequency in order to form the pre-glossary of terms. The pre-glossary of the most important terms related to our ontology and the frequency in which they appear, is described in the Table 6.

Table 6 - Glossary of Terms and Their Frequency

Dimension: 10	Alternative: 7	Ranking order: 2
Ranking profile: 5	Decision matrix: 2	Result: 8
Criterion: 3	Weight: 5	Profiles: 3

A subsequent step is the validation of the set of requirements, followed by the prioritization of the requirements. The criteria for the validation of the requirements include the following topics: correctness, completeness, consistency, verifiability, understandability, unambiguity, conciseness, realism, modifiability and traceability [277, 278, 279, and 280]. Consequently, the requirements of the MOBVR ontology had been examined against the before mentioned validation criteria and qualified and each requirement has been prioritized; priority has been also assigned to each group of CQs and to each individual CQ in a group.

Step 4: Define the classes and the class hierarchy

We followed a top down development process in order to create our ontology, meaning that we started with the definition of the most general terms and then with the more specialized concepts. The resulting ontology is presented in the Figure 18.

Step 5: Define the properties of classes—slots

The data properties of the MOBVR ontology are the following: “has_weight”, “has_input”, “has_ranking_order”, “has_output”, “has_veto_threshold”, “has_indifference_threshold”, “has_preference_threshold”, “has_credibility_index”, “has_concordance_index” and “has_disconcordance_index”. The object properties of the ontology are the following “is_alternative”, “includes” and “belongs_to”.

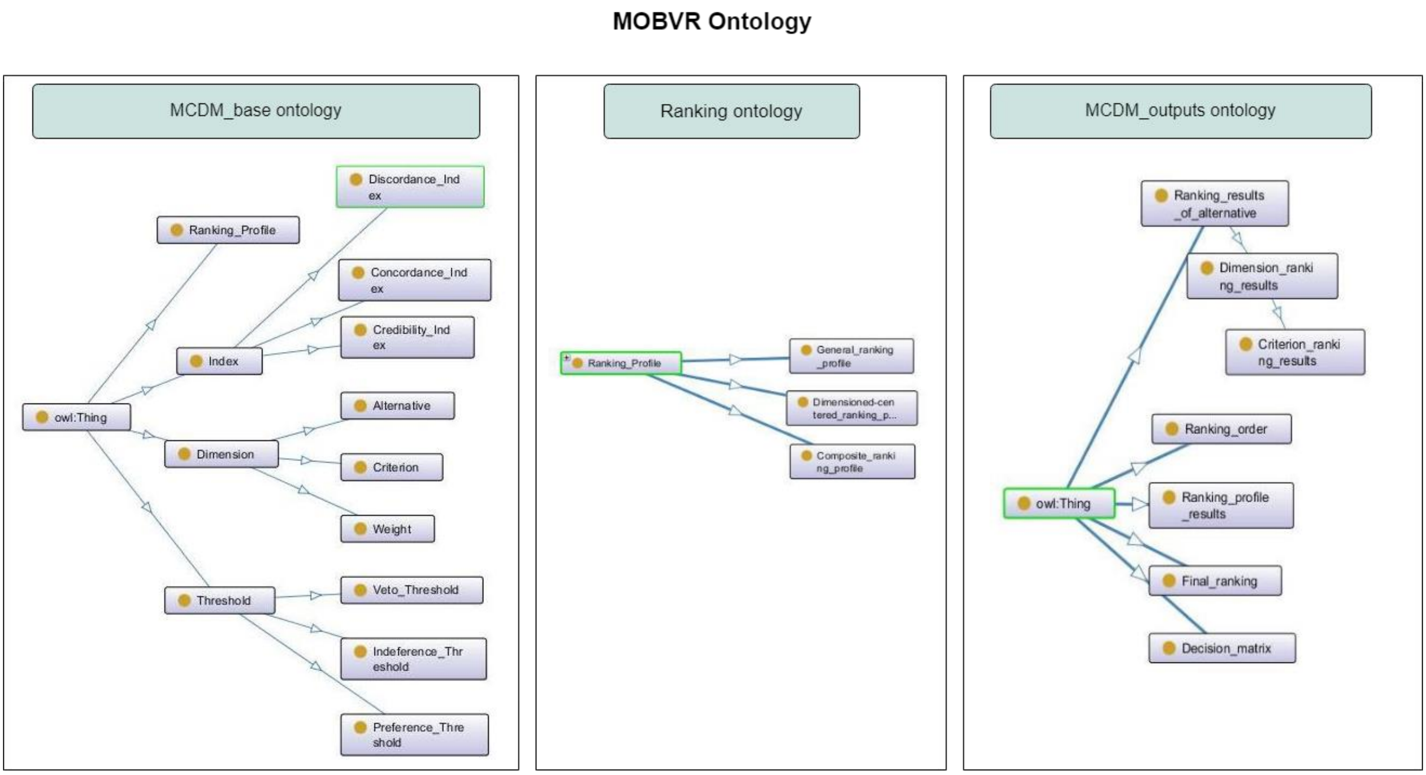


Figure 18 – Overview of the MOBVR domain-independent parts of the ontology

Step 6: Define the facets of the slots

Slot cardinality: The property "has_weight" has single cardinality, while the properties "has_input", "has_ranking_order", "has_output", have multiple cardinality. The following properties of the MOBVR ontology "has_veto_threshold", "has_indifference_threshold", "has_preference_threshold" have single cardinality. The properties "has_credibility_index", "has_concordance_index" and "has_disconcordance_index" have also single cardinality. The property "is_alternative" has single cardinality, whereas the properties "includes" and "belongs_to" have multiple cardinality.

Slot-value type: The domain of the property "has_weight" is the class Criterion and its range is interger. The domain of the properties "has_veto_threshold", "has_indifference_threshold", "has_preference_threshold" is the class Criterion, while their range is Integer. The properties of the MOBVR ontology "has_credibility_index", "has_concordance_index" and "has_disconcordance_index" have the class Criterion as their domain and their range is Integer.

Domain and range of a slot: The property "is_alternative" has the class Alternative as its domain and the class Ranking Profile, Dimension and Criterion as its range, whereas the property “includes” has Ranking Profile and Dimension as its domain and Dimension and Criterion as its range respectively. The domain of the property “belongs_to” can be Dimension and Criterion, while its range can be Ranking Profile and Dimension. The property “has_input” has the class Ranking profile as its domain and the class Decision matrix as its range, while the property “has_ranking_order” has the class Ranking profile as its domain and the class Ranking order as its range. Finally, the property “has_output” has the class Ranking profile as its domain and the class Ranking profile results as its range.

Step 7: Create instances

The instances of the MOBVR ontology are created by the MOBVR system. More specifically, the instances of the ontology components MCDM base ontology and ranking ontology are created via the alignment of the terms of the specified domain ontology, while the MCDM outputs ontology is instantiated with the results of the ontology-based ELECTRE III algorithm on the indicated domain.

4.5.4 MCDM method

The selected MCDM method is the ELECTRE III algorithm, which is composed by a vast amount of criteria. In the MOBVR framework, the ELECTRE III method is extended to handle also dimensions (e.g. categories of the criteria), the process of which is valuable on some domains. The algorithm is depicted in the MOBVR ontology, the inputs and the process in the MOBVR-base and its results in the MOBVR-outputs. As a direct consequence, the decision making method can altered to better fit the problem at hand.

4.5.4.1 Algorithm

In this section the steps of the ELECTRE III procedure are described.

1) The start point of this procedure is the decision matrix. The parameters that are required by the ELECTRE III and must be determined in order for the algorithm to proceed are p_i, q_i and v_i.
2) The next step is the computation of the concordance index for each criterion:

$$C_i(a,b) = \begin{cases} 0, \text{ if } g_i(b) \geq g_i(a) + p_i(g_i(a)) \\ 1, g_i(b) \leq g_i(a) + q_i(g_i(a)) \\ \frac{g_i(a)+p_i(g_i(a))-g_i(b)}{p_i(g_i(a))-q_i(g_i(a))}, \text{ otherwise} \end{cases}$$

3) Then the overall concordance index must be calculated:

$$C(a,b) = \frac{\sum w_i C_i(a,b)}{\sum w_i}$$

4) The subsequent step is the estimation of the discordance index for each criterion:

$$D_i(a,b) = \begin{cases} 0, \text{ if } g_i(b) \leq g_i(a) + p_i(g_i(a)) \\ 1, g_i(b) \geq g_i(a) + v_i(g_i(a)) \\ \frac{g_i(b)-g_i(a)-p_i(g_i(a))}{v_i(g_i(a))-p_i(g_i(a))}, \text{ otherwise} \end{cases}$$

If no veto threshold (v_i) is specified D_i(a,b)$= 0$ for all pairs of alternatives.

5) Followed by the calculation of the credibility index:

$$S(a,b) = \begin{cases} C(a,b), if \quad D\_i(a,b) \leq C(a,b) \; \forall \, i \\ C(a,b) \prod_{D_I(a,b)>C(a,b)} \frac{1-D_i(a,b)}{1-C(a,b)}, \text{otherwise} \end{cases}$$

If no veto thresholds (v_i) are specified S(a,b) = C(a,b) for all pairs of alternatives.

6) The last step of the procedure is the definition of the rank order:

iv. First the descending distillation takes place:

6.1) Determine the maximum value of the credibility index: $\lambda_{max} = maxS(a,b)$.

6.2) Calculate $\lambda = \lambda_{max} - (0{,}3 - 0{,}15\lambda_{max})$. Where -0.15 and 0.3 are the preset up values of distillation coefficients, α and β.

6.3) For each alternative α determine its λ-strength, i.e. the number of alternatives b with S(a,b) > λ

6.4) For each alternative a determine its λ-weakness, i.e. the number of alternatives b with (1- (0.3 - 0.15λ)) * S(a,b) > S(b,a)

6.5) For each alternative determine its qualification, i.e. the difference between λ-strength and λ-weakness.

6.6) The set of alternatives with largest qualification is called the first distillate (D1).

6.7) If D1 has more than one alternative, repeat the process on the set D1 until all alternatives have been classified. If there is a single alternative, than this is the most preferred one. Then continue with the original set of alternatives minus the set D1, repeating until all alternatives have been classified.

v. Then, the ascending distillation:

This is obtained in the same way as the descending distillation but at step 6.6, the set of alternatives have the lowest qualification forms the first distillate.

vi. And ultimately, the final ranking:

There are several ways how to combine both orders. The most frequent is the intersection of two outranking relations: *aRb* (*a* outranks *b* according to *R*) if and only if *a* outranks or is in the same class as *b* according to the orders corresponding to both relationships.

4.5.5 Visual analytics approach

In the MOBVR approach, the visual analytics combine visual representations, such as parallel coordinates and radar chart visualizations with semi-automated analytical process over the data. Visual analytics facilitate the presentation of the multidimensional information and when it is needed the visual analytics are complemented with semantic decision rules (SDR – described in the section 3.3.4.4). The visual analytics in this approach are designed to take as input the results of the MOBVR process and therefore are structured according to the MCDM-outputs ontology (part of the generic components of the MOBVR ontology).

4.6 Domain specific aspects of the MOBVR system

To deeper explore the problem and present the potential benefits from the MOBVR framework, the framework is implemented in two domains. The application of the MOBVR framework to academic ranking (i.e. case study 1 – academic multidimensional ranking) and world development ranking (i.e. case study 2 – world development ranking) also showcases the process of defining the domain specific aspects of the framework. Both the presented case studies suffice the requirements of our method. Moreover, the decision making on both cases calls for a multidimensional approach that can successfully handle the information dense presentations of the resulting decision making outputs, as well as the data on which they are based. The reason why we have chosen to apply the proposed methodology in more than one disciplines was to demonstrate the dynamic characteristics of our approach and the sequence of steps that need to be followed in case of applying the methodology to another domain. In this section, we will describe, how the process can be modified to be utilized in new application domains.

4.6.1 Case study 1: Academic multidimensional ranking

The case study of academic multidimensional ranking is focused on the evaluation of educational entities (i.e. academic units). Academic units have complex and multilevel character, with manifold aspects and constituents. The information related to academia includes all the aspects of academic activities and interactions. Academic units can range from academic departments and faculties, to whole academic institutions. Such units have many different missions and roles, in which they are dedicated and their performance on which define their status and their success. This information can be used to produce insights about the level in which an academic unit fulfills its tasks and reaches its goals. In order for such a unit to show in clear and unambiguous way its performance, all the related information must be accessible to the involved parties. The potential stakeholders of academic institutions who may benefit from this information involve: faculty, current and prospective students, potential collaborators as well as policy and decision makers of academic institutions and society at large.

Academic information can be used for numerous purposes, including academic profiling, networking and collaboration building, institutional accountability, quality assurance, strategic planning and ranking, as well as decision making in the context of academia. Profiling, networking and collaboration building in the academic setting can be achieved when the academic and research information is available via a web interface to the involved parties. Higher Educational Institutions (HEIs) are accountable to the responsible government agencies and the society in general. The quality assurance of academic units is an intricate process [146] based on methods and tools for capturing past performance and measuring future capability, while strategic planning signals the future steps of an institution so as to realize its goals. The academic rankings capture the attempt of academic units to excel [148] and they indicate the status of an institution compared to other academic units. They can be used as a measure of the development of an academic unit in time and in relation to other academic units, as well as a guide for the future development. HEIs' evaluation and decision making is built around indicators including the quality of teaching, research, services provided, and offered curricula [147].

Nowadays, in order to evaluate and correlate universities worldwide, global rankings and rankings in general are employed. However, academic institutions rankings are susceptible to problems, such as: i) the fact that they favor research universities, ii) they do not consider the preferences of the decision makers iii) the rank is institution-wise, iv) some of them are applied only on a group of universities, which is already defined as good, v) or all the universities at once. To elaborate, the majority of the rankings tend to discriminate in favor of research focused universities and to overlook the diversity of the purposes and obligations of academic institutions [50], due to the fact that most of the rankings consider only criteria related to research, whereas other rankings that consist of a variety of academic criteria, assign greater weights to the research criteria [50]. If the rankings have fixed weights and thresholds, then they express the perspective of the designers of the rankings. As a direct consequence, the rankings become biased and they do not express the opinion of the decision maker. Additionally, most of the rankings evaluate the whole institutions and not each department within universities. Nevertheless, each department of an institution has different purpose, belongs in a different sector and has different performance in relation to other academic institutions. Moreover, there are rankings that are applied only on a predefined group of universities, which is a-priori considered as the universities with the highest performance, resulting to prejudiced outputs. Other approaches rank all the Higher Education Institutions at once, which causes complications related to the data aggregation [51]. Another problem related to academic rankings is that the data on which they are based, as well as the procedure itself are not disclosed. On the contrary, they reveal only their results, which correspond to the ranking order of the alternatives. However, this results to irreproducible and obscure rankings [52].

As a direct consequence, when ranking academic units, we must take into account the before mentioned issues and take corrective measures. First of all, all the aspects of the academia must be considered in the process of evaluating the academic performance, not only the research related indicators. The rankings should also be personalizable. To elaborate, the criteria and their weights, the scope (university-wise, department-wise), as well as the subjects (selected universities, faculties or departments) of the rankings should also be altered to cover the needs and mirror the opinions of the decision makers. Moreover, rankings have better results if they are applied in groups of similar institutions, which mean that a classification should be applied upon the universities to be ranked.

4.6.1.1 Background

In this section, the existing academic ranking approaches will be described, including research focused approaches, such as the Times Higher Education (THE) [51], the Shanghai ranking [53], as well as the Leiden ranking approach [54], and more global approaches that take into account more aspects of the academic setting, like the U-Multirank [50], the CHE (Center for Higher Education) ranking [55] and the Taiwanese college navigator method [56].

The Times Higher Education ranking approach utilizes thirteen criteria grouped in: teaching, knowledge transfer, research, international outlook and industry income-innovation and focuses more on the research related indicators, thus these indicators have a greater weight than the rest indicators. Furthermore, the universities which the THE method ranks result from the list of world's leading research universities by Thomson Reuters. This approach highlights the reputation indicators that tend to favor the already known universities. Another ranking, the Shanghai ranking involves six, research related, indicators. Two of the indicators are related to the awards won, i) the amount of Nobel prizes of alumni (alumni), and ii) the number of Nobel prizes of faculty (award), while there are four indicators that capture research quality: the number of highly cited researchers (HiCi), the total number of research publications in Nature and Science journals (NCS), the amount of articles indexed in the science citation and the social science citation index (PUB) and the weighted average of the scores of the before mentioned indicators divided by the amount of the academic excellence (PCP) [57]. The ranking results are distorted by the utilization of the weighted average of indicators that have been previously calculated. This ranking method has been widely criticized. It has been characterized as irreproducible [52], poorly conceived [269] and unsuitable for evaluations and benchmarking [270]. The Leiden ranking, which is a global university ranking, is based on bibliometric data and comprises three citation index indicators: the mean citation score (MCS), the mean normalized citation score (MNCS) and the proportion of top 10% publications (PPtop10%), as well as four indicators about scientific collaboration: the proportion of collaborative publications (PPcollab), the proportion of international collaborative publications (PPint collab), the mean geographical collaboration distance (MGCD) and the proportion of the long distance collaborative publications (PP>1000km) [54]. However, all the indicators considered in the Leiden ranking are research-related.

The U-Multirank represents a multidimensional ranking approach, which is the main output of an EU funded project. This approach examines the ranking of HEIs on the following subdomains of academia: teaching – learning, research, knowledge transfer, international orientation, national engagement and third mission. It assesses all the universities and colleges. The CHE University ranking implicates the following criteria: i) student body and ii) outcomes, iii) international orientation, iv) infrastructure, v) labor market, vi) research, vii) teaching and learning, viii) study location and university and ix) the overall assessment by students, as well as x) professors [55]. The before mentioned ranking assesses departments and among its core objectives are the following: i) to support the student choice and ii) to enable the institutions to discover their strengths and their weakness. CHE ranking classifies the ranked results in three groups, while the departments in each group are ordered alphabetically, rather than displaying the ranked order of the alternatives. CHE ranking presents all criteria for all the alternatives, contributing to increased difficulty of reading the results. Another ranking approach, the Higher Education Evaluation and Accreditation Council of Taiwan (HEEACT)'s College Navigator in Taiwan comprises the following indicators: academic survey, student quality, faculty resources, library acquisitions, research grant, research output, teaching quality, learning output and international outlook [56]. The College Navigator in Taiwan is personalizable and includes predefined criteria. It also allows the user's to define their preference related to location, size, type and discipline of the academic institution. The HEEACT ranking is applied in a pre-selected group of the top 500 institutions.

In the aforementioned global rankings the users cannot choose the level of comparison (i.e. university-wise, faculty-wise, or department-wise). To elaborate, most of the rankings are occupied with whole institutions, while the assessment in lower administrative levels would be beneficial in several cases. Moreover, none of these rankings implicates ontologies, visual analytics or MCDM on its core. Last but not least, the rankings described above cannot be used in other contexts, because they have been developed especially for the academic domain.

Apart from the university rankings described in the above paragraphs, there are several cases in which MCDM methods were used on the academic field. To be more specific, ELECTRE III, VIKOR, AHP and TOPSIS have been utilized on the academic sector for ranking universities purposes.

An ELECTRE III-based method has been proposed in a three tier web system for British academic institutions rankings [271], which utilized two different user interfaces, one for novice and another for more advance users. As mentioned in their evaluation, this method was effective and considered by its users as better than similar methods [271]. In a VIKOR-based method, universities were ranked based solely on their academic performance [272]. In the before mentioned approach, a VIKOR method with equal weights was used, while varying weights were computed with respect to the sizes of variation of the normalized variables. Then a comparison of the equal weights and varying weights was implemented. A hybrid MCDM ranking method employed AHP to weight the performance evaluation indices of universities and VIKOR in order to determine each university's weighted performance values upon the relative weights of AHP [273]. Afterwards, the ranking process was implemented. In another approach, a TOPSIS method is implemented on a type-2 fuzzy set, which was used to score and assess the indicators and the alternatives in order to reduce the uncertainty and to produce more accurate outputs [274]. After determining the weights of the criteria, the university ranking is obtained by applying the type-2 fuzzy interval TOPSIS steps.

All the presented MCDM-based methods are domain specific. They do not support the use of ontologies, thus they are not dynamic. The above mentioned methods cannot support another MCDM algorithm, since they are not developed to sustain such modifications.

4.6.1.1.1 Sampling and sampling sizes

The data gathered concerns the academic activities and collaborations that take place in the departments of a Higher Education Institution (HEI). The type of information collected refers to:

1. Educational activity about all the academic departments in a HEI, derived from each academic department.
2. The results of student questionnaires.
3. Research projects information for all the departments of the Faculty of Technological Applications.
4. Research publication information about all the departments.

The data spans from 2013 to 2016 and is limited to the information available through the institutional websites; European Union research projects related repositories, and publicly available reports (i.e. the research activities report of the Faculty of Technological Applications).

4.6.1.1.2 Data collection

The information that is required for conducting the academic rankings is accumulated through data aggregation mechanisms. A different aggregation mechanism was used for each data format. The data was gathered from institutional databases, renowned online research databases (Scopus, dblp, etc.) and websites of academic departments. In the following paragraphs, we will demonstrate how the data were aggregated from the disparate sources. The data from research online databases and from academic websites were collected with the appropriate methods depending on their formats, csv-aggregation module has been developed for handling csv formats, a respective module has been developed for managing json formats, and an online database aggregator for services provided by online research databases. The data that were available in institutional databases and records were also appended in the system.

The collected academic information, not only has to be accessible and open to the possible users, but it should also be reusable. Usually this information is dispersed among various institutional databases. By accumulating all the related data in one information system that complements and does not replace the already existing systems, the management and the utilization of the information gets more efficient and easier for all the involved stakeholders of academia. In case this information is used for assessment purposes, it is also of significant to ensure its transparency by confirming the validity and the reproducibility of the applied processes and the achieved results. Linked Open Data unifies the data accumulated from disparate sources and also guarantees the above mentioned requirements. Moreover, LOD assure the validity and the reproducibility of both the ranking process and its outputs.

4.6.1.2 Conceptualization of the academic domain

The activities that occur within academic institutions range from education, research and cooperation with other academic institutions or the industry to administrative duties. Hence, there is a wide variety of modeling approaches for the academia. Yet, each conceptualization shifts the focus on a different facet of the academic setting, and accordingly each derived domain model has diverse scope. The most significant conceptualization schemes of academia are classified in the following groups: i) research, ii) education and iii) academic, with the latter involving research, education and other concepts pertinent to academia.

The research related modeling approaches concentrate on researchers, research products and procedures of academic units and include the following approaches: CASRAI (Consortia Advancing Standards in Research Administration Information) and CERIF (Common European Research Information Format). The CASRAI standards involve the terminology of the semantics and the structure of research related information [66], the research impact and life-cycle [67], whereas CERIF is a canonical reference data model for data and metadata about research concepts and the associated relationships [68, 69]. The education focused conceptualization approaches implicate different concepts of education and correspond to OMNIBUS, HERO, Ontoural, Ontology of Instructional Items and AIISO (Academic Institution Internal Structure Ontology). The OMNIBUS ontology for instance provides a thorough modeling of learning instruction, instructional design, as well as the occurrences of education [70], the Ontology of Instructional Items models the "instructional semantics" of learning resources terminology [71], while the Ontoural ontology, covers the conceptualization of ontology-based learning environments by representing the actors and the contexts of the learning process and was developed within the OURAL project [73]. Another modeling approach, the AIISO ontology captures the internal organization of Higher Education Institutions [74]. The academic ontologies comprise HERO (Higher Education Reference Ontology), Univ-Bench (University Benchmark), as well as VIVO and are usually more focused on one of the involved domains. HERO ontology captures the features of universities [76], whereas Univ-Bench models academia and also enables the assessment of Semantic Web repositories [77]. The VIVO-ISF (Integrated Semantic Framework) ontology [75] constitutes the foundation of the VIVO open source semantic web application and involves research objects (publications in journals, conferences, publication of books, equipment) and relationships (collaborations between faculty members), and a small number of concepts to model basic educational objects and relationships, which include the actors (professors, personnel) and several educational products (course, workshop, event, etc.). Although, there are many different modeling approaches to represent the academic setting, they do not involve all the aspects of HEIs, nor the required interconnections for the evaluation and the ranking of academia. Furthermore, they do not regard academia as an area with multiple dimensions, and as a result they fail to capture its multi-faceted character.

The aim of the proposed domain ontology for the academia, the AcademIS (Academic Information Systems), is to capture information about all the academic activities and collaborations that take place in HEIs, as well as the people that interact in academic institutions. The AcademIS ontology reuses VIVO and extends it so as to also capture educational activities and collaborations. VIVO, which is a part of the Linked Open Data movement, reuses widely known ontologies: the Bibontology, the Dublin Core Elements, the Dublin Core Terms, the Event Ontology, the Friend-Of-A-Friend (FOAF), the Geopolitical, the Provenance support, the Research resources, the Scientific research, the Simple Knowledge Organization System (SKOS), as well as Vitro public ontology and VIVO core, which were developed for VIVO [275, 276]. It aims to make the institutional data of HEIs widely available, interoperable and extendable [275]. The components that are important for the conceptualization of the research activities and collaborations within an academic unit and have been reused in the AcademIS ontology are the following: Person, Organization, Research, Event, Location, Course and Activity. However, as mentioned before VIVO does not model information related to the educational collaboration networks that are formed within an academic institution, and other teaching activities that are useful for professors and students of HEIs.

The newly introduced concepts in the AcademIS ontology include teaching collaborations, courses and courses collaborations information, for instance prerequisites (courses), proposed and completed thesis topics, scholarships, internships, etc. The dimensions considered in our approach are Research, Education, Cooperation with industry, Local involvement and Internationalization. Each of these domains is further analysed based on the following issues: activities, collaborations, evaluation, social responsibility and the impact of academic institution. The proposed approach introduces indicators for capturing the academic social responsibility (the environmental, social and cultural research projects, the support to students and academics with special needs, the support to special causes and the alumni associations).

Table 7- Dimensions and criteria for the academic domain grouped based on the dimension they belong to and their context

	Research	**Education**	**Cooperation with industry**	**Local involvement**	**Internationalization**
Activities	Researchers' interests	Curricula,	Services/ Products		
		Courses			
		Educational resources	Internships		
		Learning methods			
Collaborations	Research projects	Alumni associations	Cooperation with organization	Cooperation with organization	Cooperation with organization
				Cooperation in research projects	Cooperation in research projects
				Coauthorship	Coauthorship
	Publications			Inter-university cooperation	Inter-university cooperation
				Interdepartmental cooperation	Shared curricula
				Shared curricula	Satellite curricula
Evaluation	Citations	Students' questionnaires			

	Metrics	Student/professor ratio			
		Graduation ratio			
Social responsibility	Environmental, social & cultural projects	Support/ services to students/ academics with special needs	Scholarship	Support to special causes	Support to special causes
Impact of academic unit	Measure of research impact (rule)	Measure of educational impact (rule)	Measure of industry impact (rule)	Measure of local impact (rule)	Measure of international impact (rule)

4.6.1.2.1 Ontology design & implementation

Step 1: Determine the domain and the scope of the ontology

Table 8 – AcademIS ontology requirements specification [295]

Purpose
The purpose of building the AcademIS ontology is to provide a knowledge model of the academic domain. The AcademIS (Academic Information System) ontology will be used as a basis for the facilitation of the academic records management about education and research, allowing the modeling of processes like academic networking and quality assurance. It will be also used to assist visual analytics and visualizations with decision support techniques.
Scope
The domain of our ontology is the academic activities and collaborations that happen in HEIs and includes both research and education aspects of institutions.
Implementation Language
The ontology has been implemented in OWL 2.
Intended End Users
The intended end users are the policy makers of academic institutions, the quality assurance unit and the faculty.
Intended Uses
The main indented use of the ontology is the facilitation of the academic ranking.
Ontology requirements
i) Non-functional requirements
The non-functional requirements of the AcademIS ontology are the following: The ontology should support English language. The terminology that is used in the ontology must be consistent to the terms used in the HEIs.
ii) Functional requirements
An excerpt of the competency questions for AcademIS ontology: i) Do the collaborators of a professor in the research coincide with the collaborators in the courses that he/she teaches?

ii) What are the characteristics that we consider when we want to decide who is the most influential or the most distinguished researcher?
iii) What information do we need about the course and the educational experience to determine the competency of an academic?
iv) What information do we need about an academic to determine the level of his/her progress?
v) Are most active researchers (having the most publications) the ones that bring more grants to the institution?
vi) How participation in research affects the educational activities of an academic?
vii) How research activities of an academic affect the institution in terms of cooperation with other HEIs and organizations?

Competency questions

The competency questions are used to extract the terminology, the concepts, of the ontology and its frequency. From the competency answers and questions the glossary of terms of the developed ontology is determined. The competency questions that are created in the context of developing the AcademIS ontology are thoroughly described in this section. The competency questions were grouped in several clusters according to their theme and focus.

Education

1. What information do we need about the course and the educational experience to determine the competency of an academic?
2. What are the obligations of professors of HEIs?
3. What are the types of professors/ educators in a HEI?
4. Which types of assessment of the educational process exists?
5. Who asses the educational process?
6. In what form are the results of educational process?
7. What are the types of courses in terms of setting (lab, theory, etc.)?
8. Does the same educator take part in the theory and laboratory of a course?
9. Does a professor collaborate with the same educators in his/her courses?
10. What are the prerequisites for someone to teach a course?
11. How an academic create the material of his/her course?
12. Is the material of the course up to date?
13. Do the references of the course are available?
14. Does the course include the use of ICT (Information and communications technology) technologies?
15. Do the students participate in this course?

16. How many theses are supervised by the specific professor?
17. Are they successful?
18. How many theses are related to a specific course's subject?
19. How many students are enrolled in each semester?
20. How many semesters are in the curriculum?
21. What are the courses that are provided by the academic institution?
22. What obligations do the students have in order to fulfill their studies?
23. What is the educational context that an academic institution offers?
24. Are there collaborations with other universities in terms of the offered curricula?
25. What are the degrees that an HEI offer?
26. What is the amount of the offered degrees?
27. What is the amount of the students that actually graduate?
28. What learning methods does an academic utilize to develop his/her course?
29. What kind of educational sources does an academic use in his/her course?
30. Does a professor become mentor to his/her students?
31. What are the characteristics of undergraduate students that participate in graduate school?
32. In which organizations the student takes his/her internship?
33. Which is the duration of internships?
34. Are there any relations between the research interests of a student and the internship/ graduate program that he/she choose?

Research

35. What are the characteristics that we consider when we want to decide who is the most influential or the most distinguished researcher?
36. Do the researchers with the most publications are the ones that bring more grants to the institution?
37. How the research activities of an academic affect the institution in terms of cooperation with other HEIs and organizations?
38. What are the research collaborations of an academic in his/her institution?
39. What are the researcher collaborations of an academic with external collaborators?
40. What are the types of research?
41. Do researchers create research groups within the academic institutions?

42. How is the research assessed?
43. What are the obligations of an academic in terms of research?
44. What kinds of research projects are there?
45. How a successful research project is defined?
46. What are the outputs of a research project?
47. How the researchers are funded?
48. What are the obligations of a researcher?
49. What activities do an academic in terms of research?
50. What types of publications are there?
51. How the publications are assessed?
52. How the research projects are assessed?
53. What are the obligations of researchers for their publications?
54. What metrics are there to assess the research?
55. What amount of citations is considered successful?
56. What are the criteria that assist a researcher to admit a scientific paper to a journal?
57. What are the criteria that assist a researcher to participate in a conference?
58. Are the courses that an academic teaches related to his/her research interests?
59. How many grants does a researcher bring to the academic institution?
60. What kinds of cooperation are there in research projects?
61. Are there any projects that the researcher work in with other affiliation that his/her academic institution?
62. Is the academic institution informed about them?

Administrative

63. What kinds of academic institutions are there?
64. What types of funding agencies are there?
65. What kind of administrative tasks has an academic?
66. What kinds of faculty are there in an academic institution?
67. What academic departments are there in an academic institution?
68. How the academic institution is structured?
69. How the faculty is structured?

Cooperation with the industry

70. Does the academic institution cooperate with the industry?

71. How many organizations cooperate with the academic institution?
72. What are the types of cooperation between the academic institution and the organizations?
73. Does the institution's faculty coauthor publications with researchers from the industry?
74. Does the institution cooperate with organizations in research projects?
75. Do organizations offer scholarships to students of the academic institution?

Regional engagement

76. How many regional organizations offer internship positions for the students of the academic department?
77. Does the institution's faculty coauthor publications with researchers from regional organizations?
78. Does the institution cooperate with regional organizations in research projects?
79. Does the academic institution offer shared curricula along with other regional academic institutions?

Internationalization

80. Does the institution's faculty coauthor publications with researchers from foreign organizations?
81. Does the institution cooperate with foreign organizations in research projects?
82. Does the academic institution offer shared curricula along with other foreign academic institutions?
83. Does the academic institution offer satellite curricula along with other foreign academic institutions?

Social responsibility

84. Are there any alumni-oriented projects?
85. Does inter-university cooperation exists?
86. Is the university collaborates with high schools?
87. Does the university promote collaboration with business?
88. Does international cooperation exist?
89. Are there any socio-cultural and ecological projects?
90. Does the academic institution supports and promotes special causes?
91. Does the academic institution offers accessibility services for the students with special needs?

Academic

92. Do the collaborators of a professor in the research coincide with the collaborators in the courses that he/she teaches?
93. What information do we need about an academic to determine the level of his/her progress?
94. How the participation in research affects the educational activities of an academic?
95. Must an academic be also a researcher?
96. What other activities may an academic do depending on his/her profession?
97. How these activities are measured?
98. Do the other activities (professional, research or artistic) of an academic overlap with his/her responsibilities in terms of time?
99. How the research outcomes are used in the offered courses?
100. With how many organizations does an academic institution collaborate?
101. With how many other academic institutions does an academic institution collaborate?
102. Does the academic institution have up-to-date cv for the faculty members?
103. What is the amount of academics that do not have any other occupation than education?
104. Are the academics that are concerned only with education more productive than others?
105. What are the roles of an academic in an academic institution?
106. What assessment tools does an academic institution provide?

Step 2: Consider reusing existing ontologies

The AcademIS ontology reuses the VIVO-ISF ontology, which represents research as well as some education aspects, activities and collaborations in an academic unit. The upper ontologies of VIVO (Table 9) are the following: the Bibontology, the Dublin Core Elements, and the Dublin Core Terms, the Event Ontology, the Friend-Of-A-Friend (FOAF), the Geopolitical, the Provenance support, the Research resources, the Scientific research and the Simple Knowledge Organization System (SKOS).

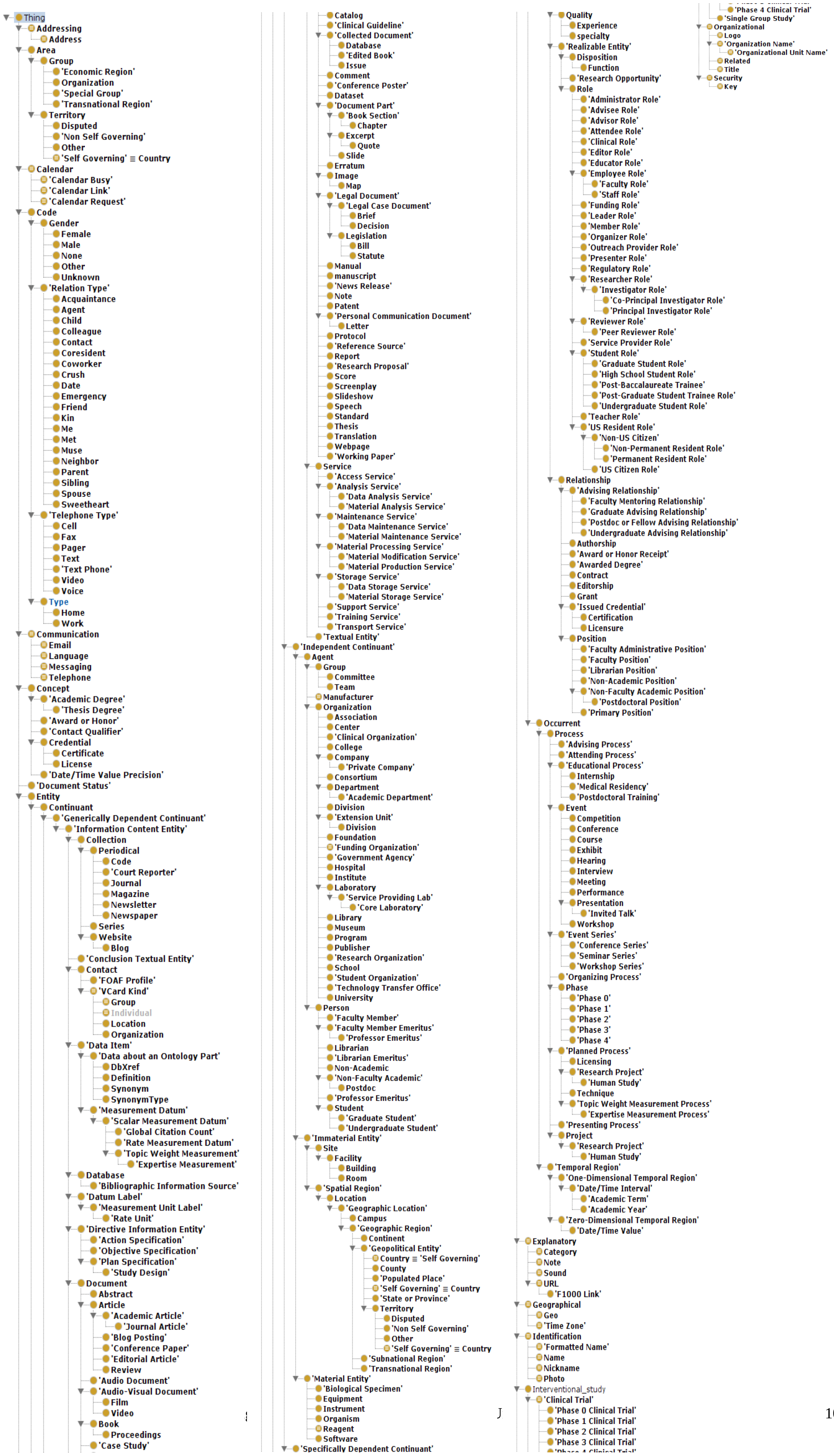


Figure 19 – VIVO-ISF ontology

As mentioned before, VIVO does not involve a thorough approach of educational concepts and relationships, nor quality terms about academia. It does not incorporate connections between education and research. Moreover, the foundation ontologies already define several basic concepts of the academic endeavors, such as researchers, professors, research projects, courses, but fail to gasp the connections that exist among these concepts and the evaluations processes that correspond to these concepts. Besides these missing fields, other concepts are also left out, like students, mentorships, citation count of the papers, educational materials that are used in the courses and so on.

Table 9 – Ontologies that AcademIS reuses

Ontology	**Namespace**	**Prefix**
Bibontology	http://purl.org/ontology/bibo/	bibo
Dublin Core elements	http://purl.org/dc/elements/1.1/	dcelem
Dublin Core terms	http://purl.org/dc/terms/	dcterms
Event Ontology	http://purl.org/NET/c4dm/event.owl#	event
FOAF	http://xmlns.com/foaf/0.1/	foaf
geopolitical.owl	http://aims.fao.org/aos/geopolitical.owl#	geo
Provenance support	http://vivoweb.org/ontology/provenancesupport#	pvs
Research Resources (eagle-i)	http://purl.obolibrary.org/obo/	ero
Scientific Research	http://vivoweb.org/ontology/scientificresearch#	scires
SKOS	http://www.w3.org/2004/02/skos/core#	skos
Vitro Public Ontology	http://vitro.mannlib.cornell.edu/ns/vitro/public#	vitropublic
VIVO core	http://vivoweb.org/ontology/core#	Vivo

Apart from the above ontologies that were used as a basis for the AcademIS ontology, the LODE-BD (Linked Open Data-enabled bibliographical data) recommendations were taken into account. "LODE-BD recommendations" is a document that provides guidelines for data providers in order to generate LOD-ready data related to bibliographic resources. To elaborate, it includes guidelines for describing resources such as articles, theses, conference papers, research reports, learning outcomes, etc. [5].

Step 3: Enumerate important terms in the ontology

The AcademIS ontology describes the activities and the collaborations that take place in an academic institution and reveal the relations that are forming within the various activities of an academic institution. The academic activities, and the subtypes of academic activities, which are the courses and the publications, the academic and the related subtypes, which are the researcher and the professor, the citations of a researcher and the students are several of the most important terms of the ontology. During the ontology design process, the terminology and its frequency were extracted in order to form the pre-glossary of terms. The pre-glossary of the most important terms related to our ontology and the frequency in which they appear, is described in the Table 10. A subsequent step is the validation of the set of requirements, followed by the prioritization of the requirements. The requirements of the AcademIS ontology identified during the ontology design phase had been examined against the before validation criteria and qualified and each requirement has been prioritized; priority has been also assigned to each group of CQs and to each individual CQ in a group.

Table 10 - Pre-glossary of Terms and Their Frequency [295]

People	**Organizational**	**Academic activities**
Academic:32	Institution:41	Course:29
Professor:24	Organization:12	Educational process:16
Researcher:22	Department:7	Educational material:12
Collaborator:20	Funding agency:8	Learning method:10
Student:15	Grant:11	Thesis:14
Faculty:9	Administration:9	Curriculum:10
Relationships	**Cooperation with the industry**	Degree:20
Mentorship:10		Research interests:25
Internship:7		Research project:31
Supervision:4	**Regional engagement**	Research:30
Collaboration:13		Publications:25
Evaluation		Journal:10
Citation count:20	**Internationalization**	Conference:11
Evaluation process:17		**Social responsibility**

Step 4: Define the classes and the class hierarchy

A top down development process was followed so as to create our ontology, meaning that the process started with the definition of the most general terms and then with the more specialized concepts. Except from the classes that existed in the VIVO ontology, we also defined the following classes: Faculty, Professor, Researcher, Outsourcer, Laboratory assistant, Educational material, Mentorship, Research interests, Educational resource, Learning method, Evaluation process. We have followed the class hierarchy of the original VIVO-ISF ontology and we have added the required extra concepts following the same logic that the ontology. The resulting ontology is presented in the Figure 20.

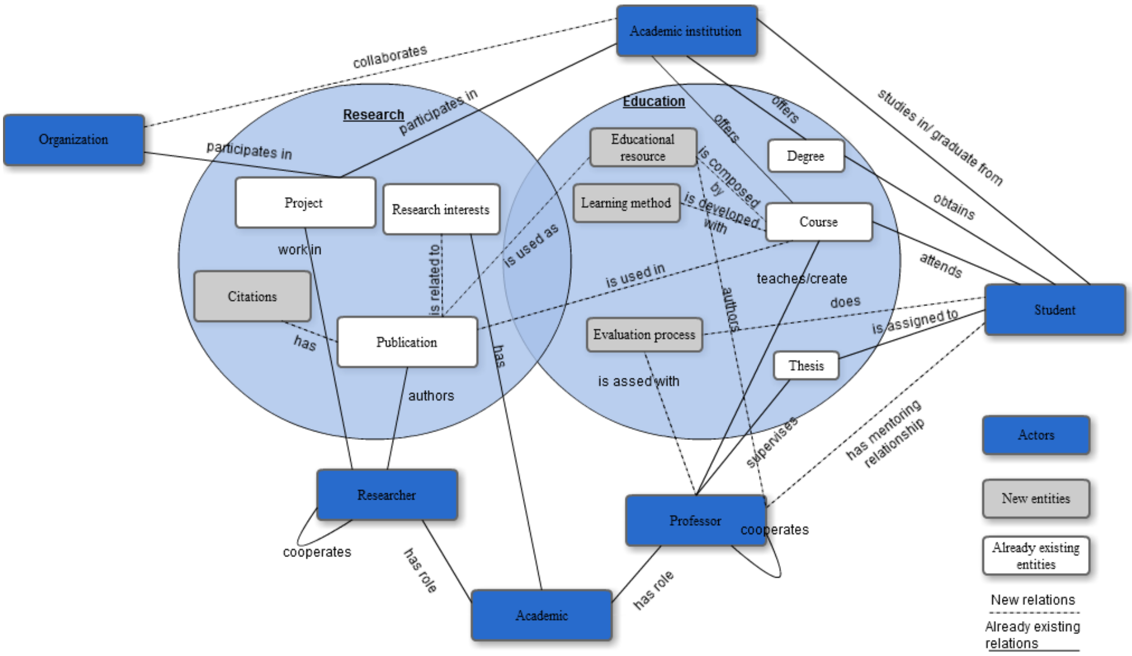


Figure 20 – Overview of the AcademIS domain model [295]

Step 5: Define the properties of classes—slots

The additional properties that we define are the following: a datatype property the “citation count”, and the object properties “is used as”, “is used in”, “is developed with”, “is composed by”, “is assessed with”, “does”, “has mentoring relationship”.

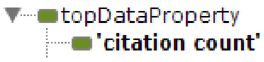


Figure 21 – The additional data property

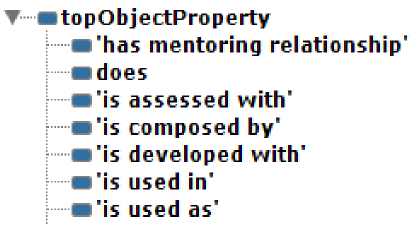


Figure 22 – The additional object properties

Step 6: Define the facets of the slots

Slot cardinality: “has mentoring relationship” has multiple cardinality; the property “does” has also multiple cardinality. The object property “is assessed with” has single cardinality for a given period of time. The “is composed by” has multiple cardinality, whereas the "is developed with" has single cardinality. The object property "is used in" has multiple cardinality, while the "used as" has single cardinality.

Slot-value type: "citation count", which is a data property with the class Article as its domain and integer as its range.

Domain and range of a slot: the "is used as" is an object property with domain the article and educational resource as its range, the object property "is used in" has the domain article and the object course as its range, the range of the object property "is developed with" is the learning method and its domain is the object course. The object property "is composed by" has the class course as domain and the class educational resource as range. Another object property that we have defined is the "is assessed with" with domain professor and laboratory assistant and range the class evaluation process. The object property "does" refers to the class student as its domain and the evaluation process as its range, while the "has mentoring relationship" has both domain and range the class person.

Step 7: Create instances

The instances of the AcademIS ontology are created through the AcademIS information system. The AcademIS information system uses the AcademIS ontology to structure the data and it creates individual instances based on the ontology.

The ontology is used as the backbone of a linked data service. The aim of the linked data service is the facilitation of the entire spectrum of activities and collaborations that are created in the premises of an academic institution, between academic institutions or even among the academic institutions and other organizations. More information about the way that the ontology is accessed and utilized by the system is referred in the third chapter of the dissertation.

For further reference, the ontology [288] and its documentation [291] are available online.

4.6.1.3 The ranking model for academia

The following dimensions arise for the evaluation of the HEI setting: education, research, cooperation with the industry, local involvement and internationalization. Each dimension incorporates several criteria, which have impact on the performance of the academic unit and denotes the quality of the offered services of academic institutions [36], [37]. The conceptualization, the management and the evaluation of the educational activity are tasks of great importance that assists identification of the level of growth in an academic unit [38].

Academics have to educate the students by integrating innovation trends in their teaching [45]. However, the quality of education, unlike the quality of research, is not documented and promoted correctly [45], [46], [47]. As a direct consequence, the academics that transcend in education [45] should be recognized. So the educational achievements should be depicted in a comparable and countable manner. Academics should be connected to other academics, students, collaborators and funding opportunities [38]. Moreover, the management of research data has changed [39] and the need for free and easily accessible online research information has been emphasized [40]. The involved stakeholders should access all the research information [41]. However, as mentioned before, research information is currently distributed in numerous systems and there is the need for interoperability [42].

Research information systems involve the data input and the utilization of reused data, while standards and already existing data sources should be employed. Additionally, the data should be overviewed by domain experts. The involved stakeholders should access the required data in a convenient format, [43] and the research must follow rules in order to assure the quality of its results [44]. The research and education interconnections should be also examined. The collaborations of academic, including the industry and the university collaborations, both local and international should be also capture. In the case of university ranking, the dimensions that we consider are education, research, cooperation with the industry, regional engagement and internationalization. Each dimension contributes with a specific weight to the procedure (Table 12).

Table 11 – The dimensions of academic ranking and their weights

Dimensions	**Weights**
Education	30%
Research	30%
Cooperation with the industry	20%
Regional engagement	10%
Internationalization	10%

Table 12 - The criteria of each dimension of academic ranking and their weights

Education		**Research**		**Cooperation with the industry**		**Regional engagement**		**Internationalization**	
Quantitate indicators	65%	Research projects per academic	15%	Amount of research projects in cooperation with the industry per academic	40%	Number of collaborations in research projects with regional enterprises	30 %	Number of collaborations with foreign organizations in research projects per academic	20%
Qualitative indicators	35%	Amount of citations	15%						
Student-staff ratio	25%	Research publication outputs per academic	15%	Amount of publications with industry per academic	40%	Amount of publications with regional organizations	30 %	Amount of publications with foreign organizations per academic	20%
Graduation rate	15%								
Student satisfaction related to courses	15%								
Qualifications of academics	10%	Completed PhD dissertations per academic	10%	Amount of offered scholarships	20%	Amount of shared curricula with regional institutions	25 %	Percentage of international students	15%
Interdisciplinary character of curriculum	10%	Amount of international awards	10%			Internships in regional organizations	15 %	Amount of shared curricula with foreign institutions	15%
Student satisfaction related to staff	10%	Number of interdisciplinary research activities	10%					Amount of satellite curricula with international institutions	15%
Student satisfaction related educational resources	5%	Amount of art related outputs	10%					Percentage of international academic staff	15%
Student satisfaction related to learning methods	5%	Post-doc positions	10%						
		Amount of patents	5%						

Each dimension consists of several individual indicators that contribute to the particular dimension. The individual indicators and their weights are described in the following paragraphs. Note that the weights of the indicators of each dimension count up to 100%. Academic units involve numerous domains that influence their performance and contribute to their character and their profile. Composite academic profiles combine the individual dimensions of academia in order to respond to certain needs.

Apart from criteria and dimensions, the proposed approach enables the composition of profiles that consist of the individual dimensions. A dimension can be part of more than one profile. The profiles that have been identified for the academic domain and that are considered necessary for the tasks of the proposed academic system are the academic excellence, which measures the academic performance in the strictest sense, the collaborations, which captures all the types of collaborations that happen within a HEI and the geographic-based collaborations, which estimates the collaborations that occur within a geographical context. The dimensions that correspond to more than one profile have been noted in italics.

Table 13 – The identified profiles in academia and their corresponding dimensions

Academic excellence	**Collaborations**	**Geographic-based collaborations**
Education	Cooperation with the industry	*Regional engagement*
Research	*Regional engagement*	*Internationalization*
	Internationalization	

4.6.1.3.1 Mathematical modeling for multi-criteria ranking

4.6.1.3.2 The application of the algorithm in our case

To calculate the dimensions:

For C_{ed} the respective weight is $w_{ed} = 0.3$.

For C_{res} the weight is $w_{res} = 0.3$.

For C_{coop_ind} the weight is $w_{coop\_ind} = 0.2$.

For C_{reg_eng} the respective weight is $w_{reg\_eng} = 0.1$.

For C_{inter} the corresponding weight is $w_{inter} = 0.1$.

1- Determine the preference threshold, the indifference threshold and the veto threshold for each dimension that correspond to p_i, q_i and v_i.

2- The concordance index for each criterion is calculated:

$$C_{ed}(a,b) = \begin{cases} 0, \text{ if } g_{ed}(b) \geq g_{ed}(a) + p_{ed}(g_{ed}(a)) \\ 1, g_{ed}(b) \leq g_{ed}(a) + q_{ed}(g_{ed}(a)) \\ \frac{g_{ed}(a)+p_{ed}(g_{ed}(a))-g_{ed}(b)}{p_{ed}(g_{ed}(a))-q_{ed}(g_{ed}(a))}, \text{ otherwise} \end{cases}$$

$$C_{res}(a,b) = \begin{cases} 0, \text{ if } g_{res}(b) \geq g_{res}(a) + p_{res}(g_{res}(a)) \\ 1, g_{res}(b) \leq g_{res}(a) + q_{res}(g_{res}(a)) \\ \frac{g_{res}(a)+p_{res}(g_{res}(a))-g_{res}(b)}{p_{res}(g_{res}(a))-q_{res}(g_{res}(a))}, \text{ otherwise} \end{cases}$$

$$C_{coop\_ind}(a,b) = \begin{cases} 0, \text{if } g_{coop\_ind}(b) \geq g_{coop\_ind}(a) + p_{coop\_ind}(g_{coop\_ind}(a)) \\ 1, g_{coop\_ind}(b) \leq g_{coop\_ind}(a) + q_{coop\_ind}(g_{coop\_ind}(a)) \\ \frac{g_{coop\_ind}(a)+p_{coop\_ind}(g_{coop\_ind}(a))-g_{coop\_ind}(b)}{p_{coop\_ind}(g_{coop\_ind}(a))-q_{coop\_ind}(g_{coop\_ind}(a))}, \text{ otherwise} \end{cases}$$

$$C_{reg\_eng}(a,b) = \begin{cases} 0, \text{ if } g_{reg\_eng}(b) \geq g_{reg\_eng}(a) + p_{reg\_eng}(g_{reg\_eng}(a)) \\ 1, g_{reg\_eng}(b) \leq g_{reg\_eng}(a) + q_{reg\_eng}(g_{reg\_eng}(a)) \\ \frac{g_{reg\_eng}(a)+p_{reg\_eng}(g_{reg\_eng}(a))-g_{reg\_eng}(b)}{p_{reg\_eng}(g_{reg\_eng}(a))-q_{reg\_eng}(g_{reg\_eng}(a))}, \text{ otherwise} \end{cases}$$

$$C_{inter}(a,b) = \begin{cases} 0, \text{ if } g_{inter}(b) \geq g_{inter}(a) + p_{inter}(g_{inter}(a)) \\ 1, g_{inter}(b) \leq g_{inter}(a) + q_{inter}(g_{inter}(a)) \\ \frac{g_{inter}(a)+p_{inter}(g_{inter}(a))-g_{inter}(b)}{p_{inter}(g_{inter}(a))-q_{inter}(g_{inter}(a))}, \text{ otherwise} \end{cases}$$

3- Then the overall concordance index is calculated:

$$C(a,b) = \frac{w_{ed}C_{ed}(a,b)+w_{res}C_{res}(a,b)+w_{coop\_ind}C_{coop\_ind}(a,b)+w_{reg\_eng}C_{reg\_eng}(a,b)+w_{inter}C_{inter}(a,b)}{w_{ed}+w_{res}+w_{coop\_ind}+w_{reg\_eng}+w_{inter}}$$

$$=\frac{0.3C_{ed}(a,b)+0.3C_{res}(a,b)+0.2C_{coop\_ind}(a,b)+0.1C_{reg\_eng}(a,b)+0.1C_{inter}(a,b)}{0.3+0.3+0.2+0.1+0.1}$$

$$=0.3C_{ed}(a,b) + 0.3C_{res}(a,b) + 0.2C_{coop\_ind}(a,b) + 0.1C_{reg\_eng}(a,b) + 0.1C_{inter}(a,b)$$

4- The subsequent step is the estimation of the discordance index for each criterion:

$$D_{ed}(a,b) = \begin{cases} 0, \text{ if } g_{ed}(b) \le g_{ed}(a) + p_{ed}(g_{ed}(a)) \\ 1, g_{ed}(b) \ge g_{ed}(a) + v_{ed}(g_{ed}(a)) \\ \frac{g_{ed}(b)-g_{ed}(a)-p_{ed}(g_{ed}(a))}{v_{ed}(g_{ed}(a))-p_{ed}(g_{ed}(a))}, \text{ otherwise} \end{cases}$$

$$D_{res}(a,b) = \begin{cases} 0, \text{ if } g_{res}(b) \le g_{res}(a) + p_{res}(g_{res}(a)) \\ 1, g_{res}(b) \ge g_{res}(a) + v_{res}(g_{res}(a)) \\ \frac{g_{res}(b)-g_{res}(a)-p_{res}(g_{res}(a))}{v_{res}(g_{res}(a))-p_{res}(g_{res}(a))}, \text{ otherwise} \end{cases}$$

$$D_{coop\_ind}(a,b) = \begin{cases} 0, \text{if } g_{coop\_ind}(b) \le g_{coop\_ind}(a) + p_{coop\_ind}(g_{coop\_ind}(a)) \\ 1, g_{coop\_ind}(b) \ge g_{coop\_ind}(a) + v_{coop\_ind}(g_{coop\_ind}(a)) \\ \frac{g_{coop\_ind}(b)-g_{coop\_ind}(a)-p_{coop\_ind}(g_{coop\_ind}(a))}{v_{coop\_ind}(g_{coop\_ind}(a))-p_{coop\_ind}(g_{coop\_ind}(a))}, \text{ otherwise} \end{cases}$$

$$D_{reg\_eng}(a,b) = \begin{cases} 0, \text{ if } g_{reg\_eng}(b) \le g_{reg\_eng}(a) + p_{reg\_eng}(g_{reg\_eng}(a)) \\ 1, g_{reg\_eng}(b) \ge g_{reg\_eng}(a) + v_{reg\_eng}(g_{reg\_eng}(a)) \\ \frac{g_{reg\_eng}(b)-g_{reg\_eng}(a)-p_{reg\_eng}(g_{reg\_eng}(a))}{v_{reg\_eng}(g_{reg\_eng}(a))-p_{reg\_eng}(g_{reg\_eng}(a))}, \text{ otherwise} \end{cases}$$

$$D_{inter}(a,b) = \begin{cases} 0, \text{ if } g_{inter}(b) \le g_{inter}(a) + p_{inter}(g_{inter}(a)) \\ 1, g_{inter}(b) \ge g_{inter}(a) + v_{inter}(g_{inter}(a)) \\ \frac{g_{inter}(b)-g_{inter}(a)-p_{inter}(g_{inter}(a))}{v_{inter}(g_{inter}(a))-p_{inter}(g_{inter}(a))}, \text{ otherwise} \end{cases}$$

If no veto threshold (v_i) is specified D_i(a,b)= 0 for all pairs of alternatives.

5- Followed by the calculation of the credibility index:

$$S(a,b)= \begin{cases} C(a,b), if \quad D_i(a,b) \leq C(a,b) \, \forall \, i \\ C(a,b) \prod_{D_I(a,b)>C(a,b)} \frac{1-D_i(a,b)}{1-C(a,b)}, \text{otherwise} \end{cases}$$

If no veto thresholds (v_i) are specified $S(a,b)= C(a,b)$for all pairs of alternatives.

6- The last step of the procedure is the definition of the rank order:

vii. First the descending distillation takes place:

6.1- Determine the maximum value of the credibility index: $\lambda_{max} = maxS(a,b)$.

6.2- Calculate $\lambda = \lambda_{max} - (0,3 - 0,15\lambda_{max})$. Where -0.15 and 0.3 are the preset up values of distillation coefficients, α and β.

6.3- For each alternative α determine its λ-strength, i.e. the number of alternatives b with S(a,b) > λ

6.4- For each alternative a determine its λ-weakness, i.e. the number of alternatives b with (1- (0.3 - 0.15λ)) * S(a,b) > S(b,a)

6.5- For each alternative determine its qualification, i.e. the difference between λ-strength and λ-weakness.

6.6- The set of alternatives with largest qualification is called the first distillate (D1).

6.7- If D1 has more than one alternative, repeat the process on the set D1 until all alternatives have been classified. If there is a single alternative, than this is the most preferred one. Then continue with the original set of alternatives minus the set D1, repeating until all alternatives have been classified.

viii. Then, the ascending distillation:

This is obtained in the same way as the descending distillation but at step 6.6, the set of alternatives have the lowest qualification forms the first distillate.

ix. And ultimately, the final ranking:

There are several ways how to combine both orders. The most frequent is the intersection of two outranking relations: aRb (a outranks b according to R) if and only if a outranks or is in the same class as b according to the orders corresponding to both relationships.

To calculate the indicators within the dimensions:

a. In the same way, we calculate each dimension and we take into account the indicators of each dimension and their weights.

4.6.1.4 Semantic web components

The AcademIS domain model provides all the necessary tools to structure, manage, explore and query the data that are hosted in the corresponding information system. The ontology and the involved concepts and relationships of the ontology expressed in Description Logic (DL), as well as the meaning of each sentence are displayed in the Table 14. To elaborate, there is an excerpt of the TBox, RBox and ABox that describe concept hierarchies, rules and instances.

Table 14 – An excerpt of Tbox, Rbox And Abox Of Academis Ontology In Description Logic [292]

TBox	
DL	**Meaning**
Professor⊔Researcher⊑Academic	Every professor or researcher is an academic.
Professor⊑∀teachesOf.Course	A professor teaches a course.
UndergraduateStudent⊔GraduateStudent⊑Student	Every undergraduate or graduate student is a student.
ResearchOrganization⊑Organization	Every research organization is an organization.
Researcher⊓∃CoauthorOf.-⊤⊑Coauthor	A researcher, who has somebody as coauthor of, is a coauthor.
Professor⊓∃CollaboratorOf.-⊤⊑Collaborator	A professor, who has a collaborator of, is a collaborator.
Organization⊓∃CollaborationWith.AcademicDepartment ⊑ Affiliated Organization	An organization that has collaboration with academic department is an affiliated organization.
UndergraduateStudent⊑∃takesInternshipIn.RegionalOrganization	An undergraduate student takes internship in regional organization.
UndergraduateStudent⊑∃registeredIn.EducationalProgram	An undergraduate student is registered in educational program.
Evaluation⊑∀cinductedBy.Student⊔Evaluator	Every evaluation is conducted by a student or an evaluator.
RBox	
DL	**Meaning**

teacherOf≡studentOf-	teacher of and student of are inverse roles
takeInternship≡offerInternship-	take internship and offer internship are inverse roles
authorOf⊑creatorOf	author of is a subrole of creator of
ABox	
DL	**Meaning**
{Distributed Programming, Operating Systems I}⊑Course	Distributed Programming and Operating Systems I are courses
{GM, CS, IX}⊑Academics	CS, GM, and IX are academics
{TEI of Athens, University of Limoges}⊑Academic Institutions	TEI of Athens and University of Limoges are academic institutions

The contributions concerning the domain model are the concepts and the relations that describe the cooperation between academics, the assessment of the academia, the academic social responsibility and consideration of the multidimensionality of the academic units. Additionally, the proposed approach introduces semantic web rules to better support academic ranking and consists the first VIVO-based system that utilizes such rules.

SDR rules have been developed for the indicators of each dimension. A SDR set is called at each ranking position that indifference or incomparability occurs. For instance, the SDR set for "Internationalization" involves rules for the criteria of the before mentioned dimension. As a direct consequence, a rule for each criterion (Cooperation with organization, Co-authorship, Cooperation in research projects, Inter-university cooperation, Satellite curricula, Shared curricula and Support to special causes) has been developed. In case that a decision rule causes insolvability (i.e. the alternatives to be ranked on the same position), that specific decision rule is subtracted from the semantic decision rule set. Allow us to assume that criterion "Support to special causes" of the dimension "Internationalization" creates insolvability between alternatives F4 and F5 in the ranking position R1. According to algorithm 1, the resolution method is called again and the SDR for this criterion is withdrawn, leaving the dimension with the SDR for the rest indicators of the dimension. A fragment of the set of SDR for "Internationalization" dimension can be described as follows [294]:

- Faculty(?f4)^has_Amount_of_Support_to_special_causes(?f4,?sup_f4)^Faculty(?f5)^has_Amount_of_Support_to_special_causes(?f5,?sup_f5)^swrlb:greaterThanOrEqual(?sup_f4,?sup_f5)-> has_more_ Support_to_special_causes(?f4,true)
- Faculty(?f4)^has_Amount_of_Cooperations_with_Foreign_Organizations(?f4,?coop_org_f4)^Faculty(?f5)^has_Amount_of_Cooperations_with_Foreign_Organizations(?f5,?coop_org_f5)^swrlb:greaterThanOrEqual(?coop_org_f4,?coop_org_f5) ->has_more_Cooperations_with_Foreign_Organizations (?f4,true)
- Faculty(?f4)^has_Amount_of_Coauthorship_with_foreign_affiliations(?f4,?coauth_foreign_f4)^Faculty(?f5)^has_Amount_of_Coauthorship_with_foreign_affiliations(?f5,?coauth_foreign_f5)^swrlb:greaterThanOrEqual(?coauth_foreign_f4,?coauth_foreign_f5)-> has_more_Coauthorship_with_foreign_affiliations(?f4,true)
- Faculty(?f4)^has_Amount_of_coop_research_projects_with_foreign_institutions(?f4,?coop_rp_foreign_f4)^Faculty(?f5)^has_Amount_of_coop_research_projects_with_foreign_institutions(?f5,?coop_rp_foreign_f5)^swrlb:greaterThanOrEqual(?coop_rp_foreign_f4,?coop_rp_foreign_f5)-> has_more_coop_research_projects_with_foreign_institutions(?f4,true)
- Faculty(?f4)^has_Amount_of_Interuniversity_Coop(?f4,?coop_inter_uni_f4)^ Faculty(?f5)^has_Amount_of_Interuniversity_Coop(?f5,?coop_inter_uni_f5)^ swrlb:greaterThanOrEqual(?coop_inter_uni_f4,?coop_inter_uni_f5)-> has_more_ Inter_university_Coop (?f4,true)
- Faculty(?f4)^has_Amount_of_sharred_curricula_foreign_universities(?f4,?sharred_curricula_f4)^Faculty(?f5)^has_Amount_of_sharred_curricula_foreign_universities(?f5,?sharred_curricula_f5)^swrlb:greaterThanOrEqual(?sharred_curricula_f4,?sharred_curricula_f5)-> has_more_sharred_curricula_foreign_universities (?f4,true)
- Faculty(?f4)^has_Amount_of_satellite_curricula_foreign_universities(?f4,?sattellite_curricula_f4)^Faculty(?f5)^has_Amount_of_sattellite_curricula_foreign_universities(?f5,?sattellite_curricula_f5)^swrlb:greaterThanOrEqual(?sattellite_curricula_f4,?sattellite_curricula_f5)-> has_more_satellite_curricula_foreign_universities (?f4,true)
- Faculty(?f4)^has_more_Cooperations_with_Foreign_Organizations(?f4,true)^ has_more_Coauthorship_with_foreign_affiliations(?f4,true)^has_more_coop_research_projects_with_foreign_institutions(?f4,true)^has_more_Inter_university_Coop(?f4,true)^has_more_sharred_curricula_foreign_universities(?f4,true) ^has_more_satellite_curricula_foreign_universities (?f4,true)->Higher Rank in Internationalization(?f4)

Additional inspection of the data occurs in the predefined queries endpoint. A query searches the dataset for records that are equal to the defined patterns. Queries respond to questions such as “Which faculty has the greatest research impact?” generating a set of faculties and their scores on the indicators of research impact in tabular form. SPARQL predefined queries ease the decision makers to explore the dataset even if they are not familiar with Semantic Web technologies.

Table 15 – Excerpt SPQs and their SPARQL equivalent

SPQ	**SPARQL**

Find the most cited academics (with more than 50 citations at a publication).	SELECT ?academic
	WHERE
	{
	?academic authored ?publication;
	          foaf:name ?name .
	?publication has_citation ?citation;
	           ?citation>50.
	}

Show in which research projects the academic department cooperates with X organization.	SELECT ?research_project
	WHERE
	{
	   ?department participates_in ?res_project
	   FILTER(?organization_X participates_in res_project)
	}

Find the academic departments which were ranked at the top 5 ranking positions.	SELECT ?department WHERE { ?department ranked ?position }LIMIT 5

Give me all the profiles of the academia.	SELECT ?profile
	WHERE
	{
	   ?profile belong_to "academia"
	}

Find all the publications published in 2015.	SELECT ?publications
	WHERE
	{
	   ?publication year "2015"
	}

Show all the research projects of the academic department cs from 2014-2016.	SELECT ?research-program
	WHERE
	{
	   ?research-program conducted_in CS
	    FILTER (
	      ?date > "2014-01-01"^^xsd:date &&
	      ?date < "2016-01-01"^^xsd:date
	  )
	 }

Find the research collaborations of the academic.	SELECT *
	WHERE
	{
	   ?academic cooperates ?ac;
	          foaf:name ?name .
	}

Which faculty has the greatest research impact?	SELECT ?faculty
	WHERE
	{
	   {?academic belongs_to ?faculty
	    ?academic authored ?publication;
	          foaf:name ?name .
	   ?publication has_citation ?citation;
	           ?citation>50.}
	   UNION

	`{?academic participates_in ?res_project;`
	`?res_project>10.}`
	`}`

Retrieve all the courses of the post-graduate programs.	`SELECT *`
	`WHERE`
	`{`
	`?courses is_part_of ?post-graduate-program`
	`}`

4.6.1.5 The AcademIS (Academic Information System)

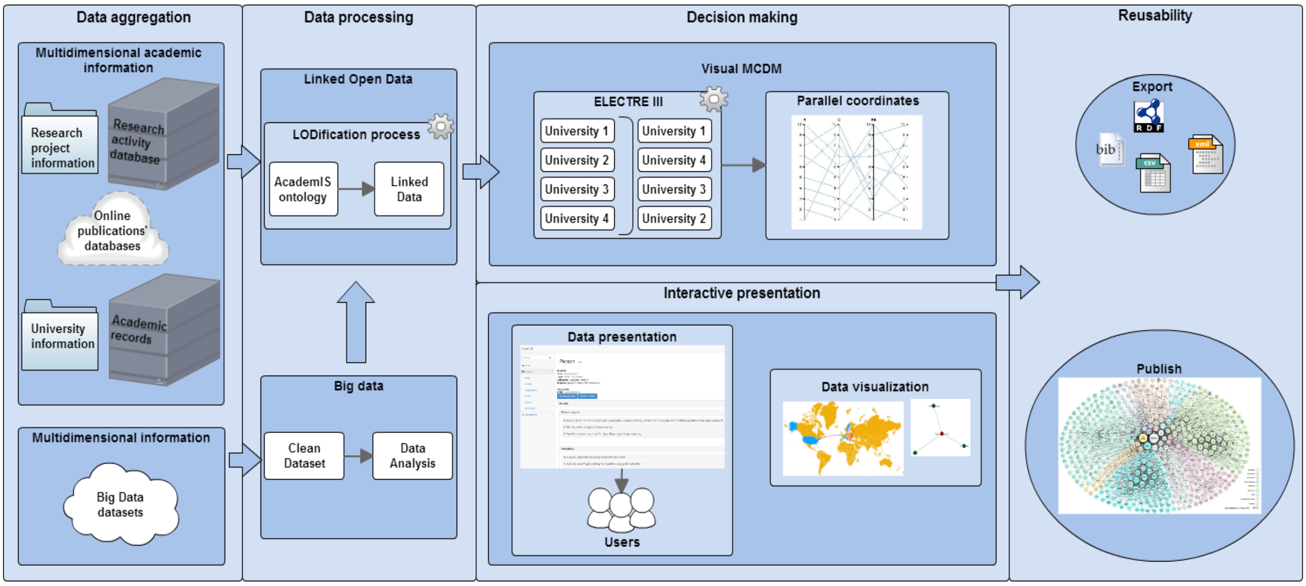


Figure 23 – System architecture specialized for the Academia [293]

The AcademIS information system integrates the different techniques and technologies and delivers a solution for multidimensional ranking and decision making on the academic setting. Even though the AcademIS information system entails high levels of complexity, this complexity is not perceived by the decision makers. All the components of the information system that may confuse and hinder the decision maker from resulting to a valid decision are displayed in easier understandable way (e.g. the voluminous and perplexed ranking information is displayed via visual analytics, the intricacy of the SPARQL queries is overleaped via their predefined and ready to use form and so on). The architecture of the AcademIS information system, which is basically the instance of the MOBVR system for the academia, is presented in Figure 23. The homepage of the AcademIS (Figure 24) provides an overview of the most important contents (i.e. people – academics, publications, etc.) of the information system and their amounts. By selecting one of the above options (for instance the research projects), the decision maker is redirected to a list of all the available records of this kind (for example all the research projects in the AcademIS). Each record is further described in a webpage, for instance Figure 25 displays information about a selected research project.

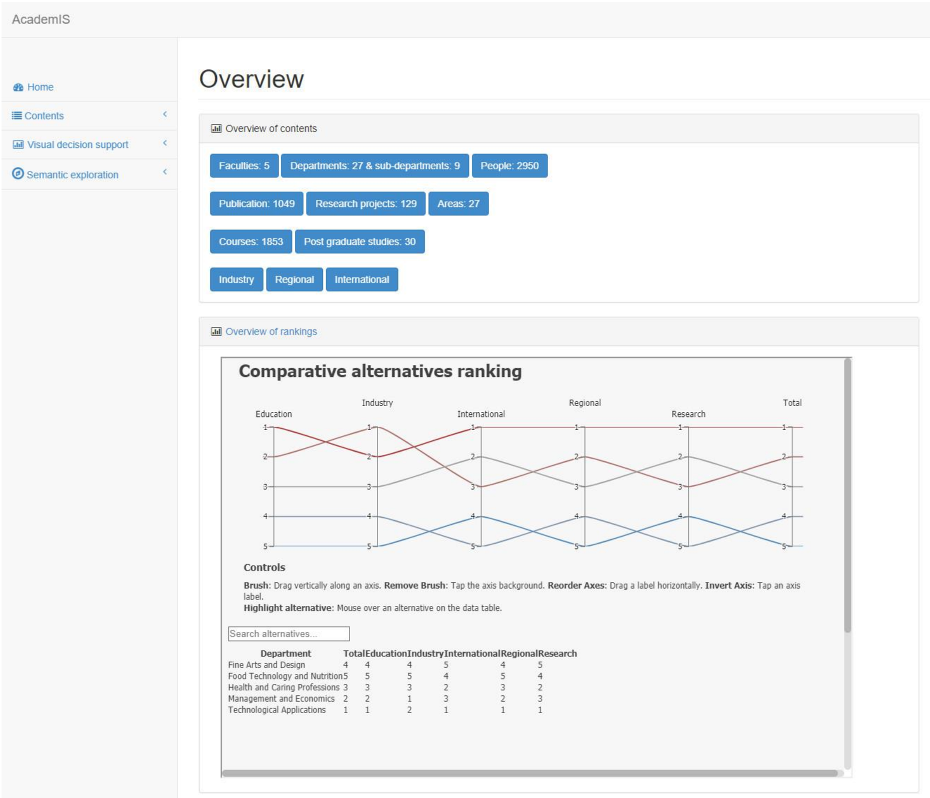


Figure 24 – Overview of the main topics of the AcademIS interface and the amount of their contents

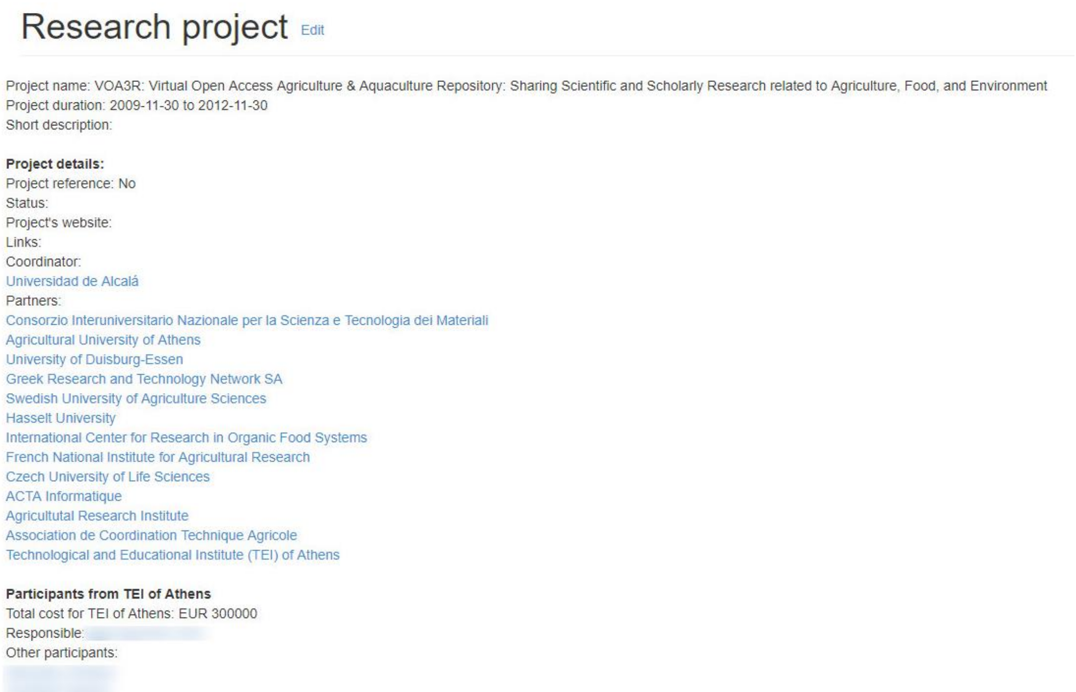


Figure 25 – The webpage for a research project and its related information

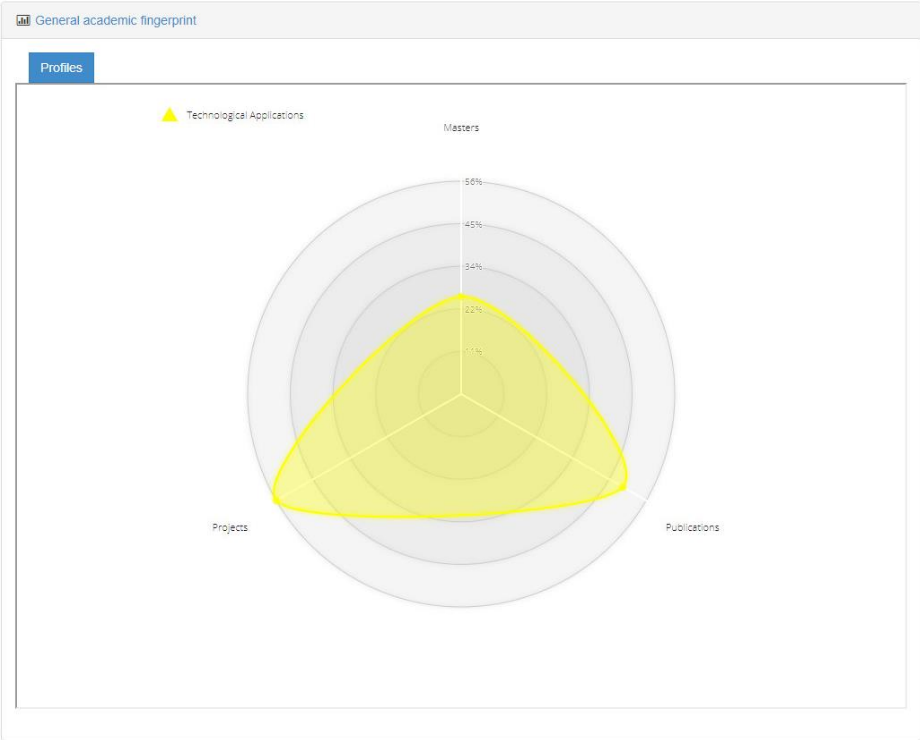


Figure 26 – Research fingerprint of an academic faculty

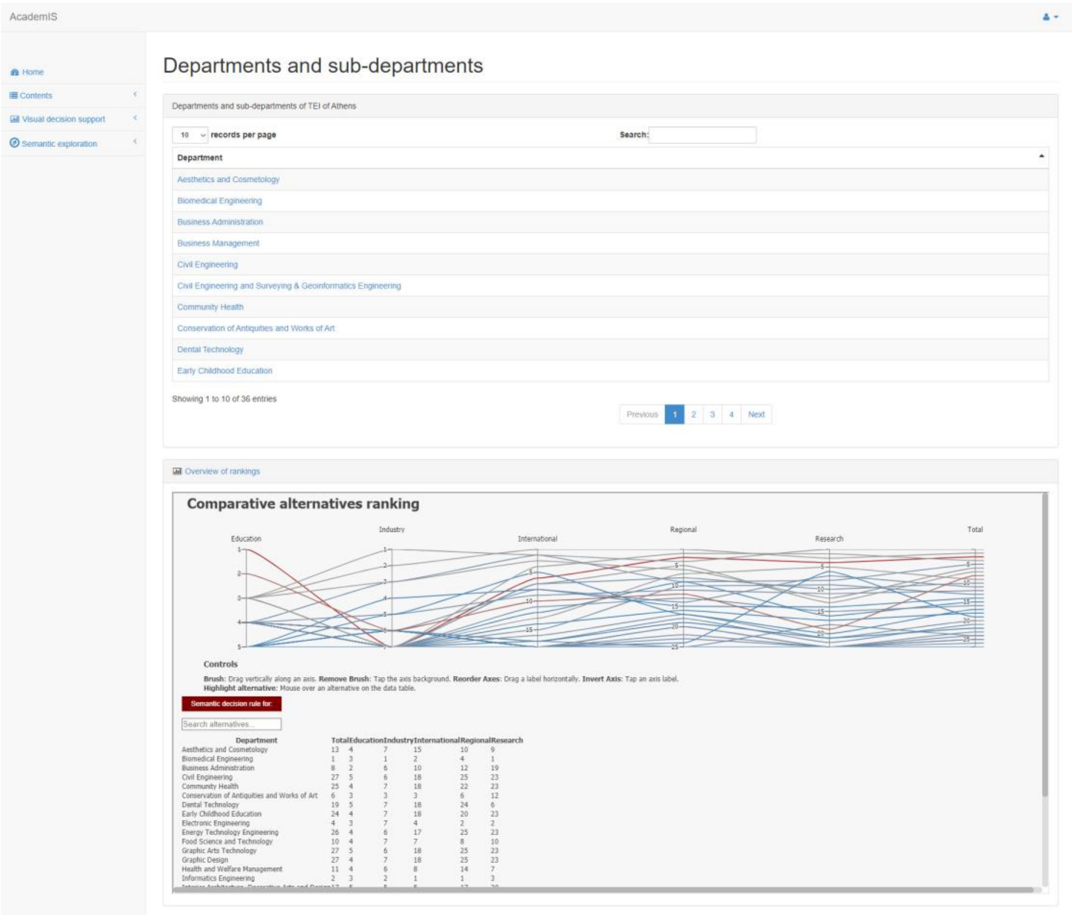


Figure 27 – Comparative ranking of the academic departments

The AcademIS web interface also gives access to the results of the MOBVR algorithm applied in the dataset, which is depicted by the Comparative Ranking of the alternatives, a visual analytics component implemented with Parallel Coordinates visualization (Figure 27). A performance fingerprint is created for each academic profile. In Figure 26, the research fingerprint for a selected academic faculty is presented.

4.6.1.6 Usage scenarios

In this section, seven indicative usage scenarios of the AcademIS system are described. Each usage scenario concerns a different group of stakeholders and explicates the way that AcademIS system facilitates their needs. A comparison of the necessary activities to perform a scenario before and after the system is also presented.

- **Student:**

Scenario: A student needs to access the information about an academic department and compare its performance with other academic units.

The implicated MOBVR component: The web interface of the AcademIS system.

Before the system: The student searches information about the academic unit. He/she accesses the website of the academic department, of the faculty and of the academic institution, so as to learn information about the academic department. The student also examines similar academic units in order to have a reference point to compare the academic department in which he/she is interested. Moreover, the student seeks the research outcomes of the academic department, as well as its collaboration, to gain a more complete view on academic department's performance.

After the system: The whole performance related information is available by the web interface of the AcademIS system. Hence, the student retrieves the required information with less effort.

- **Academic:**

Scenario: An academic requires information about the profile of an academic department to include it in a research proposal.

The implicated MOBVR component: The academic unit fingerprint.

Before the system: The academic accumulates information about the various activities that are carried out within the academic department. This task is tedious and time consuming. It also requires constant updating for future references.

After the system: The academic access the visual analytic component “academic unit fingerprint” for the desired academic profiles for the selected department. The information is updated through the system. So, the academic can easily use the related information.

- **Researcher:**

Scenario: A researcher is trying to find an academic department in which the academics have similar research interests. The researcher needs also to be reassured about its performance.

The implicated MOBVR component: The web interface of AcademIS and the academic unit fingerprint.

Before the system: The research browses the websites of several academic departments and seeks information for the conducted research. He/she searches the research databases, the research projects’ webpages and the citation information.

After the system: The researcher looks through the web interface of the system and access the research outputs of the academic department to ensure that the interests of the department coincide with his/her own interests. Then, he/she overviews the research academic unit fingerprint.

- **Industry:**

Scenario: An organization needs services and products from an academic department. Therefore, the organization wants to find out about the experience and the background of the educational department in the selected area.

The implicated MOBVR component: The web interface of AcademIS and the academic unit fingerprint.

Before the system: The organization needs to explore the previous collaborations of the academic department with the industry. The organization decides whether or not the product and services developed correlate with the current needs of the organization.

After the system: The organization accesses the academic unit's fingerprint for the dimension cooperation with the industry to acquire knowledge about the background and expertise of the department and browses the developed outcomes from the web interface.

- **Decision maker:**

Scenario: A decision maker that wants to compare the performances of academic departments and determine which is better than others.

The implicated MOBVR component: The comparative ranking of the alternatives.

Before the system: The decision maker accumulates the performance related information from many sources and in different formats. Then the information must be expressed in a common manner in order to facilitate their comparison. Finally, the decision maker decides on the preferred solution.

After the system: The information needed is already aggregated in the system and in common format. The decision maker can access the comparative ranking of the alternatives to acquire information about the performances of the various departments in the various dimensions – subdomains – of the academia. Complementary, the decision maker can consult the web interface.

- **Policy maker:**

Scenario: The policy maker needs to inspect the past and current performances of the academic departments in various dimensions, so as to conclude about the future strategic planning.

The implicated MOBVR component: The web interface of AcademIS and the comparative ranking of the alternatives.

Before the system: The policy maker accesses the records related to academic performance, measures the growth of the departments, correlates the performances of the departments and decides on the future actions to be taken.

After the system: The policy maker visits the system's comparative ranking of the alternatives and the academic unit fingerprint for the alternatives. As a result, he/she gains insights for the departments and decided on the strategic planning.

- **Potential collaborator:**

Scenario: A potential collaborator needs information about an academic department to decide on a potential collaboration.

The implicated MOBVR component: The web interface of AcademIS.

Before the system: The potential collaborator seeks information related to the academic department.

After the system: The potential collaborator accesses the profile of the academic department and gets information about its prior performance.

4.6.2 Case study 2: World Development Indicators

The case study of the World development indicators is focused on ranking of countries according to their development progress. The main aim of the WDI dataset, which is accumulated and maintained by the World Bank, is to facilitate bank operational activities. However, the dataset can be used to support a variety of other decision making tasks. The development indicators (i.e. criteria) are categorized in twenty (20) dimensions based on their subjects. For instance, the dimension “Gender” refers to criteria, which measure the development of a country that is related to the gender equity. Each dimension is thus centered on a different aspect of a country’s character that is useful for the world development ranking. These dimensions can be further used to synthesize ranking profiles, for example, the dimensions aid effectiveness, economy & growth, external debt, financial sector, poverty, private sector, public sector and trade can form the ranking profile economic development.

4.6.2.1 Background

The development progress of a country affects many facets of a country’s performance. In fact, in order to measure the development progress, these facets (i.e. indicators) should be monitored systematically. The World Bank website presents the data in basic two-dimensional graphic visualizations (e.g. country performance on indicator per year, world performance on indicator per year, etc.), which do not enable deep and comparative insights about the data set. The MOBVR system, due to its ontology-based architecture, incorporates and populates the domain model with the large WDI data set, and then processes the data with semantic web techniques and the outranking method in order to generate unambiguous ranking outputs for performance comparisons among countries. The outcomes are presented in an understandable and interactive manner, so it makes possible evidence-informed analysis and meaningful decision making.

4.6.2.1.1 Sampling and sampling sizes

The case study about the World Development Indicators (WDI) is derived from the data collected and disseminated under the Creative Commons Attribution 4.0 (CC-BY 4.0), which allows users to copy, modify and distribute data in any format for any purpose, including commercial use, by the World Bank [290] structured on 20 dimensions, with economic, social, environmental and progress indicators, independent or intersecting through dimensions. Information about 248 alternatives, of which there are 217 countries, 25 geographic-based country combinations and 6 categories classified based on the financial state of the countries, is available through the data set.

The World Development Indicators encompasses data that indicates the development of each country at national, regional and worldwide level. The World Development Indicators are focused on the following topics: 1) Agriculture & Rural Development, 2) Aid Effectiveness, 3) Climate Change, 4) Economy & Growth, 5) Education, 6) Energy & Mining, 7) Environment, 8) External Debt, 9) Financial Sector, 10) Gender, 11) Health, 12) Infrastructure, 13) Poverty, 14) Private Sector, 15) Public Sector, 16) Science & Technology, 17) Social Development, 18) Social Protection & Labor, 19) Trade and 20) Urban Development.

The individual indicators may correspond to more than one topic. The data spans form 2005 to 2016. For the years 2005-2007 and 2009 the data are biannual. There are archives about three months for the years 2008 and 2010, while in 2011 and 2013, there is available information about the world development indicators for four months. The frequency of the data collection is greater for the years 2012 and 2014, in which WDI information has been gathered for six individual months of each year. At 2015, there are archives for seven months, whereas at 2016, there are data for eight months of that specific year.

4.6.2.1.2 Data collection

The data has been aggregated to the information system via the aggregator mechanism of MOBVR, which exploited the WDI API to retrieve the information. After the accumulation of information to the system, the data is structured according to the WDI ontology. The design of the ontology and the ontology itself will be described in the next section.

4.6.2.2 Conceptualization of the world development domain

The ontology is consisted by information related to the world development. It engulfs the characteristics of development, as well as information about the countries. During the conceptualization of the domain, the relationships between the concepts that were inherent in the dataset were taken into account and were finally led to the creation of the WDI modeling scheme [289].

4.6.2.2.1 Ontology design & implementation

Step 1: Determine the domain and the scope of the ontology

Table 16 – WDI ontology requirements specification

Purpose
The purpose of building the WDI ontology is to provide a knowledge model of the world development progress domain. The WDI (World Development Indicators) ontology will be used as a basis for the facilitation of the world development rankings, allowing the modeling of the development progress indicators. It will be also used to assist visual analytics and visualizations with decision support techniques.
Scope
The domain of our ontology is the development progress indicators of countries.
Implementation Language
The ontology has been implemented in OWL 2.
Intended End Users
The intended end users are ministries, public agencies, banks, organizations, decision makers, policy makers and the public.
Intended Uses
The main indented use of the ontology is the facilitation of multidimensional rankings.
Ontology requirements
i) Non-functional requirements
The non-functional requirements of the WDI ontology are the following: The ontology should support English language. The terminology that is used in the ontology must be consistent to the terms used for development progress.
ii) Functional requirements
An excerpt of the competency questions for WDI ontology: i) How economic indicators affect the development progress of a country? ii) How many women have at least master degree? iii) What is the ratio of women with master degree to men with master degree? iv) What is the amount of mammal species that are threatened in a selected country? v) How many people are living in slums in a selected country? vi) In how many kilometers does the rural land area of a country expand? vii) How much is the external debt of a country?

Competency questions

The competency questions that are created in the context of developing the WDI ontology are thoroughly described in this section. The competency questions were grouped in several clusters according to their subject and focus.

1. How economic indicators affect the development progress of a country?
2. How many women have at least master degree?
3. What is the ratio of women with master degree to men with master degree?
4. What is the amount of mammal species that are threatened in a selected country?
5. How many people are living in slums in a selected country?
6. In how many kilometers does the rural land area of a country expand?
7. How much is the external debt of a country?
8. How many community health workers exist per 1000 people in a selected country?
9. What is the life expectancy at birth for males?
10. How much cost to export from a selected country?
11. What is the percentage of ICT goods imports?
12. What is the amount of patent applications of a country's residents?
13. Are there any children in employment?
14. How many women work part-time?
15. What is the amount of the urban population?
16. What is the percentage of the urban population with access to electricity?
17. How much development progress did a country make for a selected time period?
18. How many years lasts the compulsory education?
19. What is the amount of methane emissions?
20. What is the change of methane emissions from 1990?
21. How many are the broadband subscriptions?
22. Find the income share held by the highest 20%.
23. What country has the best performance in the dimension "Infrastructure"?
24. Find the birth rate for a specific country.
25. What is the military expenditure for a given country?
26. I would like to know the amount of scientific and technical journal articles in a country.
27. How many are the high-technology exports in a selected country?
28. How many seats are held by women in the national parliament?
29. How many men are unemployed in a given country?

30. I would like to know how many exports of goods and services take place in a country.
31. Find the export volume index for a selected country.
32. How many merchandise exports happen in a country?
33. I would like to know the time to import in days in a selected country.
34. How many people live in the largest city of a selected country?
35. Find the number of arrivals for international tourism in a country.
36. I would like to know the amount of insurance and financial services.
37. What are the indicators for the dimension "Aid effectiveness"?
38. Find the livestock production index for a selected country.
39. How many pregnant women are receiving prenatal care in a selected country?
40. How many droughts, floods and extreme temperatures happen in a country?
41. How many marine protected areas exists within a country?
42. Find the amount of nitrous oxide emissions in a country.
43. I would like to know the mortality rate under 5 for a given country.
44. What is the annual percentage population growth for a given country?
45. How much electricity is produced from renewable sources?
46. I would like to know the amount of children out of school for primary education.
47. Find the total population for a given country.
48. What is the amount of trained teachers in secondary education of a selected country?
49. How much energy is consumed in a country?
50. Find the expenditure on tertiary education of a given country.
51. How many bird species are threatened in a selected country?
52. How many births were attended by skilled health staff in a country?
53. I would like to know the literacy rate of adult male in a selected country.
54. Find the percentage of survival to age 65 for males in a given country.

Step 2: Consider reusing existing ontologies

No existing ontologies are reused for the development of the general aspects of the WDI ontology. The ontology was built in accordance with the identified concepts and their relationships in the WDI dataset.

Step 3: Enumerate important terms in the ontology

Table 17 - Glossary of Terms and Their Frequency (Excerpt)

Country: 532	Debt: 117	Savings:61
Population: 314	Education: 156	Emissions: 69
Children: 138	Import: 152	Male: 282
Savings: 61	Export: 179	Income: 99
Age: 152	Land: 66	Gross: 75
PPG: 93	Area: 65	External: 79
Female: 309	School: 80	Merchandise: 124
Rate: 141	Services: 109	Current US$: 397
Labor force: 75	Employment: 197	Net: 196
Total: 360	Goods:75	Expenditure:85

The WDI ontology describes the indicators that define the development progress of a country. The indicators involve economic, social indexes, as well as educational, technological and environmental ones. Each indicator may correspond to one or more categories (i.e. dimensions). During the ontology design process, the terminology and its frequency are extracted, in order to form the pre-glossary of terms. The pre-glossary of the most important terms related to our ontology and the frequency in which they appear, is described in the Table 17.

Step 4: Define the classes and the class hierarchy

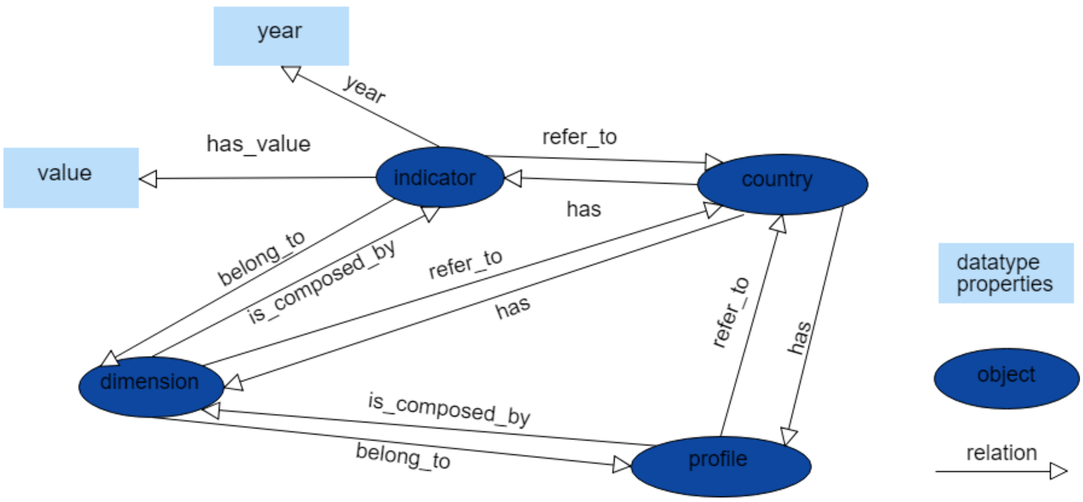


Figure 28- WDI domain model

A top down development process was followed in order to create the WDI ontology, meaning that the process started with the definition of the most general terms and then with the more specialized concepts. The following classes have been defined: Indicator, Country, Dimension and Profile. The resulting ontology is presented in the Figure 28.

Step 5: Define the properties of classes—slots

The properties that we define are the following: the datatype properties “year” and “has_value”, and the object properties “refer_to”, “belong_to”, “has” and “is_composed_by”.

Step 6: Define the facets of the slots

Slot cardinality: “year” has single cardinality, as well as “has_value”, the property “refer_to” has also single cardinality. The object property “belong_to” has multiple cardinality. The property “has” has also multiple cardinality.

Slot-value type: “year”, which is a data property with the class indicator as its domain and integer as its range. The property “has_value” is a data property as well, with the class indicator as a domain and integer as its range.

Domain and range of a slot: The property “refer_to” is an object property, its domain is “indicator”, “dimension” and “profile” and “country” as its range. The object property “belong_to” has class indicator and class dimension as domain and class dimension and profile as its range, while the property “has” is an object property with class country as its domain and the classes indicator, dimension and profile as its range.

Step 7: Create instances

The instances of the WDI ontology are created through the WDI information system. The WDI-IS information system uses the WDI ontology to structure the data and it creates individual instances based on the ontology. The ontology is used as the backbone of a linked data service. The aim of the linked data service is the facilitation of the entire spectrum of activities and collaborations that are created in the premises of an academic institution, between academic institutions or even among the academic institutions and other organizations. More information about the way that the ontology is accessed and utilized by the system is referred in the 3rd chapter (Chapter 3 - Methodology) of the dissertation.

4.6.2.3 The ranking model for world development

Table 18 - The dimensions of world development ranking and their weights

Dimensions	Weights
Agriculture & Rural Development	5%
Aid Effectiveness	2.5%
Climate Change	5%
Economy & Growth	5%
Education	10%
Energy & Mining	2.5%
Environment	5%
External Debt	2.5%
Financial Sector	10%
Gender	5%
Health	5%
Infrastructure	2.5%
Poverty	5%
Private Sector	2.5%
Public Sector	2.5%
Science & Technology	10%
Social Development	5%
Social Protection & Labor	5%
Trade	5%
Urban Development	5%

Capturing the development progress of countries requires consistent and recurrent recording of the involved indicators. The development progress is a multidimensional problem that comprises numerous indicators. In order to perform rankings in the world development setting, the indicators must be taken into account. In the proposed approach, the combination of indicators forms dimensions, while the grouping of dimensions forms profiles. Each indicator (i.e. criterion) and each dimension has different significance on the overall problem, which is declared by their weights. The dimensions of the world development progress and their corresponding weights are displayed in the Table 18.The WDI dataset implicates more than 1400 indicators categorized in 20 dimensions. An excerpt of the criteria and their corresponding weights is presented in Table 19, while the full list of criteria is available through the WDI-IS [289]. The weights of the criteria contribute to the ranking results of their dimension, while in order to conclude for the whole problem the results of each dimension (i.e. the results of a dimension correspond to the aggregation of all its criteria and their weights) contribute to the ranking according to the respective weights.

Table 19 – An excerpt of the criteria of each dimension of world development ranking and their weights

Agriculture & Rural		**Aid Effectiveness**		**Climate Change**		**Economy & Growth**		**Education**	
Agricultural land (sq. km)	2%	Net migration	2%	CO2 emissions (kt)	2%	Expense (% of GDP)	1%	Pupil-teacher ratio, preprimary	2 %
Forest area (% of land area)	0.5%	Income share held by lowest 20%	2%	Marine protected areas (% of territorial waters)	3%	Changes in inventories (constant LCU)	2%	Compulsory education, duration (years)	3%
Rural population	2%	Debt forgiveness grants (current US$)	2 %	Terrestrial protected areas (% of total land area)	2%	Exports as a capacity to import (constant LCU)	2%	Literacy rate, youth total (% of people ages 15-24)	2%
Agricultural raw materials imports (% of merchandise imports)	4%	Pregnant women receiving prenatal care (%)	3%	PFC gas emissions (thousand metric tons of CO2 equivalent)	2%	Adjusted net national income (annual % growth)	3%	Children out of school (% of primary school age)	2%
Average precipitation in depth (mm per year)	1%	Technical cooperation grants (BoP, current US$)	2%	Total greenhouse gas emissions (%change from 1990)	2%	GDP (constant 2010 US$)	2%	School enrollment, secondary (% net)	2%
Energy & Mining		**Environment**		**External Debt**		**Financial Sector**		**Gender**	
Access to electricity (% of population)	2%	Bird species, threatened	2%	Commitments, IBRD (COM, current US$)	2%	Broad money (% of GDP)	2%	Children out of school, primary, female	2%
Delay in obtaining an electrical connection (days)	1%	Population living in slums (% of urban population)	2%	Concessional debt (% of total external debt)	2%	Deposit interest rate (%)	2%	Firms with female top manager (% of firms)	1%
Energy imports, net (% of energy use)	3%	Plant species (higher), threatened	2%	Debt buyback (current US$)	3%	Inflation, consumer prices (annual %)	2%	Life expectancy at birth, male (years)	2%
Mineral rents (% of GDP)	2%	Rural land area (sq. km)	2%	Debt stock reduction (current US$)	2%	Lending interest rate (%)	2%	Progression to secondary school, male (%)	1%
Oil rents (% of GDP)	2%	Surface area (sq. km)	2%	GNI (current US$)	2%	Real interest rate (%)	2%	Lifetime risk of maternal death (%)	2%
Health		**Infrastructure**		**Poverty**		**Private Sector**		**Public Sector**	
Adults (ages 15+) newly infected with HIV	2 %	Air transport, freight (million ton-km)	3%	Population living in slums (% of urban population)	1%	Average time to clear exports through customs (days)	2%	Net lending (+) / net borrowing (-) (% of GDP)	2%
Birth rate, crude (per 1,000 people)	2%	Fixed broadband subscriptions (per 100people)	2%	Rural poverty gap at national poverty lines (%)	2%	Binding coverage, all products (%)	2%	Armed forces personnel, total	2%
Cause of death, by injury (% of total)	3%	ICT service exports (BoP, current US$)	2%	Income share held by third 20%	2%	Commercial service exports (current US$)	2%	Expense (% of GDP)	2%
Hospital beds (per 1,000 people)	4%	Individuals using the Internet (% of population)	2%	Poverty gap at $1.90 a day (2011 PPP) (%)	1%	Cost to import (US$ per container)	2%	Interest payments (% of expense)	2%
International migrant stock, total	1%	Railways, passengers carried (million passenger-km)	2%	Poverty gap at national poverty lines (%)	3%	Tax payments (number)	2%	Military expenditure (% of GDP)	2%
Science & Technology		**Social Development**		**Social Protection & Labor**		**Trade**		**Urban Development**	
High-technology exports (current US$)	2 %	Children in employment, female (% of female children ages 7-14)	3%	Children in employment, total (% of children ages 7-14)	2%	Arms exports (SIPRI trend indicator values)	2%	Population in urban agglomerations of more than 1 million	2%
Researchers in R&D (per million people)	1%	Refugee population by country or territory of asylum	2%	Coverage of social insurance programs (% of population)	2%	Bound rate, simple mean, all products (%)	3%	Population density (people per sq. km of land area)	1%
Scientific and technical journal articles	2%	Refugee population by country or territory of origin	2%	Coverage of social safety net programs (% of population)	3%	Commercial service imports (current US$)	2%	Population living in slums (% of urban population)	3%
Technicians in R&D (per million people)	3%	School enrollment, tertiary (gross), gender parity index (GPI)	2%	Labor force, total	1%	Import value index (2000 = 100)	1%	Population in largest city	1%
Trademark applications, total	4%	Vulnerable employment, female (% of female employment) (modeled ILO estimate)	2%	GDP per person employed (constant 2011 PPP $)	2%	Customs and other import duties (% of tax revenue)	2%		

Apart from criteria and dimensions, the proposed approach enables the composition of profiles that consist of the individual dimensions. A dimension can be part of more than one profile. The profiles that have been identified for the world development progress domain and are considered necessary for the tasks of the proposed system are the economic, which depicts the economic-related dimensions, the social, which captures the social aspects of the domain, the environmental that corresponds to the dimensions focused on environment and the progress, which consists of the dimensions that denote progress. The dimensions that correspond to more than one profile have been noted in italics.

Table 20 – The identified profiles in the WDI & the corresponding dimensions

economic	**social**	**environmental**	**progress**
Aid Effectiveness	Gender	Climate Change	Agriculture & Rural Development
External Debt	Health	Environment	Education
Financial Sector	*Social Development*	*Energy & Mining*	Infrastructure
Economy & Growth	Social Protection & Labor		Science & Technology
Poverty	*Poverty*		Urban Development
Private Sector			*Social Development*
Public Sector			
Infrastructure			
Trade			
Energy & Mining			

4.6.2.3.1 Mathematical modeling for multi-criteria ranking

4.6.2.3.2 The application of the algorithm in our case

To calculate the dimensions:

For C_{ar} the respective weight is $w_{ar} = 0.05$.

For C_{ae} the weight is $w_{ae} = 0.025$.

For C_{cc} the weight is $w_{cc} = 0.05$.

For C_{eg} the respective weight is $w_{eg} = 0.05$.

For C_{ed} the corresponding weight is $w_{ed} = 0.1$.

For C_{em} the respective weight is $w_{em} = 0.025$.

For C_{env} the weight is $w_{env} = 0.05$.

For C_{ex_d} the weight is $w_{ex\_d} = 0.025$.

For C_{fs} the respective weight is $w_{fs} = 0.1$.

For C_{gend} the corresponding weight is $w_{gend} = 0.05$.

For C_h the respective weight is $w_h = 0.05$.

For C_{inf} the weight is $w_{inf} = 0.025$.

For C_{pov} the weight is $w_{pov} = 0.05$.

For C_{pr_s} the respective weight is $w_{pr\_s} = 0.025$.

For C_{p_s} the corresponding weight is $w_{p\_s} = 0.025$.

For C_{st} the respective weight is $w_{st} = 0.1$.

For C_{sd} the weight is $w_{sd} = 0.05$.

For C_{spl} the weight is $w_{spl} = 0.05$.

For C_{trade} the respective weight is $w_{trade} = 0.05$.

For C_{urb_dev} the corresponding weight is $w_{urb\_dev} = 0.05$.

1- Determine the preference threshold, the indifference threshold and the veto threshold for each dimension that correspond to p_i, q_i and v_i.

2- The concordance index for each criterion is calculated:

$$C_{ed}(a,b) = \begin{cases} 0, \text{ if } g_{ed}(b) \geq g_{ed}(a) + p_{ed}(g_{ed}(a)) \\ 1, g_{ed}(b) \leq g_{ed}(a) + q_{ed}(g_{ed}(a)) \\ \frac{g_{ed}(a)+p_{ed}(g_{ed}(a))-g_{ed}(b)}{p_{ed}(g_{ed}(a))-q_{ed}(g_{ed}(a))}, \text{ otherwise} \end{cases}$$

$$C_{res}(a,b) = \begin{cases} 0, \text{ if } g_{res}(b) \geq g_{res}(a) + p_{res}(g_{res}(a)) \\ 1, g_{res}(b) \leq g_{res}(a) + q_{res}(g_{res}(a)) \\ \frac{g_{res}(a)+p_{res}(g_{res}(a))-g_{res}(b)}{p_{res}(g_{res}(a))-q_{res}(g_{res}(a))}, \text{ otherwise} \end{cases}$$

$$C_{coop\_ind}(a,b) = \begin{cases} 0, \text{if } g_{coop\_ind}(b) \geq g_{coop\_ind}(a) + p_{coop\_ind}(g_{coop\_ind}(a)) \\ 1, g_{coop\_ind}(b) \leq g_{coop\_ind}(a) + q_{coop\_ind}(g_{coop\_ind}(a)) \\ \frac{g_{coop\_ind}(a)+p_{coop\_ind}(g_{coop\_ind}(a))-g_{coop\_ind}(b)}{p_{coop\_ind}(g_{coop\_ind}(a))-q_{coop\_ind}(g_{coop\_ind}(a))}, \text{ otherwise} \end{cases}$$

$$C_{reg\_eng}(a,b) = \begin{cases} 0, \text{ if } g_{reg\_eng}(b) \geq g_{reg\_eng}(a) + p_{reg\_eng}(g_{reg\_eng}(a)) \\ 1, g_{reg\_eng}(b) \leq g_{reg\_eng}(a) + q_{reg\_eng}(g_{reg\_eng}(a)) \\ \frac{g_{reg\_eng}(a)+p_{reg\_eng}(g_{reg\_eng}(a))-g_{reg\_eng}(b)}{p_{reg\_eng}\left(g_{reg\_eng}(a)\right)-q_{reg\_eng}(g_{reg\_eng}(a))}, \text{ otherwise} \end{cases}$$

$$C_{inter}(a,b) = \begin{cases} 0, \text{ if } g_{inter}(b) \geq g_{inter}(a) + p_{inter}(g_{inter}(a)) \\ 1, g_{inter}(b) \leq g_{inter}(a) + q_{inter}(g_{inter}(a)) \\ \frac{g_{inter}(a)+p_{inter}(g_{inter}(a))-g_{inter}(b)}{p_{inter}\left(g_{inter}(a)\right)-q_{inter}(g_{inter}(a))}, \text{ otherwise} \end{cases}$$

3- Then the overall concordance index is calculated:

C(a,b)

$$=\frac{w_{ed}C_{ed}(a,b)+w_{res}C_{res}(a,b)+w_{coop\_ind}C_{coop\_ind}(a,b)+w_{reg\_eng}C_{reg\_eng}(a,b)+w_{inter}C_{inter}(a,b)}{w_{ed}+w_{res}+w_{coop\_ind}+w_{reg\_eng}+w_{inter}}$$

$$=\frac{0.3C_{ed}(a,b)+0.3C_{res}(a,b)+0.2C_{coop\_ind}(a,b)+0.1C_{reg\_eng}(a,b)+0.1C_{inter}(a,b)}{0.3+0.3+0.2+0.1+0.1}$$

$$=0.3C_{ed}(a,b) + 0.3C_{res}(a,b) + 0.2C_{coop\_ind}(a,b) + 0.1C_{reg\_eng}(a,b) + 0.1C_{inter}(a,b)$$

4- The subsequent step is the estimation of the discordance index for each criterion:

$$D_{ed}(a,b) = \begin{cases} 0, \text{ if } g_{ed}(b) \leq g_{ed}(a) + p_{ed}(g_{ed}(a)) \\ 1, g_{ed}(b) \geq g_{ed}(a) + v_{ed}(g_{ed}(a)) \\ \frac{g_{ed}(b)-g_{ed}(a)-p_{ed}(g_{ed}(a))}{v_{ed}\left(g_{ed}(a)\right)-p_{ed}(g_{ed}(a))}, \text{ otherwise} \end{cases}$$

$$D_{res}(a,b) = \begin{cases} 0, \text{ if } g_{res}(b) \leq g_{res}(a) + p_{res}(g_{res}(a)) \\ 1, g_{res}(b) \geq g_{res}(a) + v_{res}(g_{res}(a)) \\ \frac{g_{res}(b)-g_{res}(a)-p_{res}(g_{res}(a))}{v_{res}\left(g_{res}(a)\right)-p_{res}(g_{res}(a))}, \text{ otherwise} \end{cases}$$

$$D_{coop\_ind}(a,b) = \begin{cases} 0, \text{if } g_{coop\_ind}(b) \leq g_{coop\_ind}(a) + p_{coop\_ind}(g_{coop\_ind}(a)) \\ 1, g_{coop\_ind}(b) \geq g_{coop\_ind}(a) + v_{coop\_ind}(g_{coop\_ind}(a)) \\ \frac{g_{coop\_ind}(b)-g_{coop\_ind}(a)-p_{coop\_ind}(g_{coop\_ind}(a))}{v_{coop\_ind}\left(g_{coop\_ind}(a)\right)-p_{coop\_ind}(g_{coop\_ind}(a))}, \text{ otherwise} \end{cases}$$

$$D_{reg\_eng}(a,b) = \begin{cases} 0, \text{ if } g_{reg\_eng}(b) \leq g_{reg\_eng}(a) + p_{reg\_eng}(g_{reg\_eng}(a)) \\ 1, \quad g_{reg\_eng}(b) \geq g_{reg\_eng}(a) + v_{reg\_eng}(g_{reg\_eng}(a)) \\ \frac{g_{reg\_eng}(b) - g_{reg\_eng}(a) - p_{reg\_eng}(g_{reg\_eng}(a))}{v_{reg\_eng}\left(g_{reg\_eng}(a)\right) - p_{reg\_eng}(g_{reg\_eng}(a))}, \text{ otherwise} \end{cases}$$

$$D_{inter}(a,b) = \begin{cases} 0, \text{ if } g_{inter}(b) \leq g_{inter}(a) + p_{inter}(g_{inter}(a)) \\ 1, g_{inter}(b) \geq g_{inter}(a) + v_{inter}(g_{inter}(a)) \\ \frac{g_{inter}(b) - g_{inter}(a) - p_{inter}(g_{inter}(a))}{v_{inter}(g_{inter}(a)) - p_{inter}(g_{inter}(a))}, \text{ otherwise} \end{cases}$$

If no veto threshold (v_i) is specified D_i(a,b)$= 0$ for all pairs of alternatives.

5- Followed by the calculation of the credibility index:

$$S(a,b) = \begin{cases} C(a,b), if \quad D_i(a,b) \leq C(a,b) \; \forall \; i \\ C(a,b) \prod_{D_I(a,b) > C(a,b)} \frac{1 - D_i(a,b)}{1 - C(a,b)}, \text{otherwise} \end{cases}$$

If no veto thresholds (v_i) are specified $S(a,b) = C(a,b)$for all pairs of alternatives.

6- The last step of the procedure is the definition of the rank order:

x. First the descending distillation takes place:

6.1- Determine the maximum value of the credibility index: $\lambda_{max} = maxS(a,b)$.

6.2- Calculate $\lambda = \lambda_{max} - (0{,}3 - 0{,}15\lambda_{max})$. Where -0.15 and 0.3 are the preset up values of distillation coefficients, α and β.

6.3- For each alternative α determine its λ-strength, i.e. the number of alternatives b with S(a,b) > λ

6.4- For each alternative a determine its λ-weakness, i.e. the number of alternatives b with (1- (0.3 - 0.15λ)) * S(a,b) > S(b,a)

6.5- For each alternative determine its qualification, i.e. the difference between λ-strength and λ-weakness.

6.6- The set of alternatives with largest qualification is called the first distillate (D1).

6.7- If D1 has more than one alternative, repeat the process on the set D1 until all alternatives have been classified. If there is a single alternative, than this is the most preferred one. Then continue with the original set of alternatives minus the set D1, repeating until all alternatives have been classified.

xi. Then, the ascending distillation:

This is obtained in the same way as the descending distillation but at step 6.6, the set of alternatives have the lowest qualification forms the first distillate.

xii. And ultimately, the final ranking:

There are several ways how to combine both orders. The most frequent is the intersection of two outranking relations: *aRb* (*a* outranks *b* according to *R*) if and only if *a* outranks or is in the same class as *b* according to the orders corresponding to both relationships.

To calculate the indicators within the dimensions:

b. In the same way, we calculate each dimension and we take into account the indicators of each dimension and their weights.

4.6.2.4 Semantic web components

To better present the WDI ontology and the underlying concepts and relationships, the ontology expressed in Description Logic (DL) and the meaning of each sentence are displayed in the Table 21. Fragments of the TBox, RBox and ABox are presented, which respectively contain sentences that describe concept hierarchies, rules and instances. For the sake of brevity, we include only an excerpt of our ontology in DL.

Table 21 – An excerpt of Tbox, Rbox And Abox Of WDI Ontology In Description Logic [292]

TBox	
DL	**Meaning**
Country ⊑ Alternative	Every country is an alternative.
Indicator⊑∃refer_to.Country	An indicator refers to a country.
Dimension⊑∃is_composed_by.Indicator	A dimension is composed by indicator.
RBox	
DL	**Meaning**
belong_to≡is_composed_by-	Belong_to and is composed_by of are inverse roles
ABox	
DL	**Meaning**
{France, Greece}⊑Countries	France and Greece are Countries
{Access to electricity, rural (% of rural population), Agricultural irrigated land (% of total agricultural	Access to electricity, rural (% of rural population), Agricultural irrigated land (% of

land), Agricultural land (% of land area)} ⊑ Indicators	total agricultural land) and Agricultural land (% of land area) are academics
{Agriculture & Rural Development, Aid Effectiveness} ⊑ Dimensions	Agriculture & Rural Development and Aid Effectiveness are dimensions of the world development progress

Semantic Decision Rules have been introduced to solve indifference or incomparability cases in the WDI case study. A SDR set has been developed for the indicators of each dimension. For instance, the SDR set for "Urban Development" involves rules for the criteria of the before mentioned dimension. As a direct consequence, a rule for each criterion (Access to electricity, urban (% of urban population), Mortality caused by road traffic injury (per 100,000 people), PM2.5 air pollution, mean annual exposure (micrograms per cubic meter), PM2.5 air pollution, population exposed to levels exceeding WHO guideline value (% of total), Population density (people per sq. km of land area), Population in largest city, Population in urban agglomerations of more than 1 million, Population in urban agglomerations of more than 1 million (% of total population), Population in the largest city (% of urban population), Population living in slums (% of urban population), Pump price for diesel fuel (US$ per liter), Pump price for gasoline (US$ per liter), Urban land area (sq. km), Urban land area where elevation is below 5 meters (% of total land area), Urban land area where elevation is below 5 meters (sq. km), Urban population, Urban population (% of total), Urban population growth (annual %), Urban population living in areas where elevation is below 5 meters (% of total population), Urban poverty gap at national poverty lines (%) and Urban poverty headcount ratio at national poverty lines (% of urban population)) has been developed. In case that a decision rule causes insolvability (i.e. the alternatives to be ranked on the same position), that specific decision rule is subtracted from the semantic decision rule set. Allow us to assume that criterion "Population in the largest city (% of urban population)" of the dimension "Urban Development" creates insolvability between the alternatives Japan and Germany in the ranking position R25. According to algorithm 1, the resolution method is called again and the SDR for this criterion is withdrawn, leaving the dimension with the SDR for the rest indicators of the dimension. A fragment of the set of SDR for "Urban Development" dimension can be described as follows:

- Country(?Japan)^has_Population_in_the_largest_city(%of_urban_population)(?Japan,?pop_larg_city_J)^Country(?Germany)^has_Population_in_the_largest_city(%of_urban_population)(?Germany,?

pop_larg_city_G)^swrlb:greaterThanOrEqual(?pop_larg_city_J,?pop_larg_city_G)-> has_greater_ pop_larg_city_ (%of_urban_population)(?Japan,true)

- Country(?Japan)^has_Access_to_electricity,_urban(%of_urban_population)(?Japan,?access_electricity_urban_J)^Country(?Germany)^has_Access_to_electricity,_urban_(%of_urban_population)(?Germany,?access_electricity_urban_G)^swrlb:greaterThanOrEqual(?access_electricity_urban_J,?access_electricity_urban_G)-> has_greater_Access_to_electricity,_urban(%of_urban_population)(?Japan,true)
- Country(?Japan)^has_Mortality_caused_by_road_traffic_injury(per_100,000_people)(?Japan,?mort_road_traffic_J)^Country(?Germany)^has_Mortality_caused_by_road_traffic_injury(per_100,000_people)(?Germany,?mort_road_traffic_G)^swrlb:lessThanOrEqual(?mort_road_traffic_J,?mort_road_traffic_G)-> has_less_Mortality_caused_by_road_traffic_injury(per_100,000_people)(?Japan,true)
- Country(?Japan)^has_PM2.5_air_pollution,mean_annual_exposure(micrograms_per_cubic_meter)(?Japan,?PM2.5_air_pollution_J)^Country(?Germany)^has_PM2.5_air_pollution,mean_annual_exposure(micrograms_per_cubic_meter)(?Germany,?PM2.5_air_pollution_G)^swrlb:lessThanOrEqual(?PM2.5_air_pollution_J,?PM2.5_air_pollution_G)-> has_less_PM2.5_air_pollution,mean_annual_exposure(micrograms_per_cubic_meter)(?Japan,true)
- Country(?Japan)^has_PM2.5_air_pollution,_population_exposed_to_levels_exceeding_WHO_guideline_value(%of_total)(?Japan,?PM2.5_air_pollution_exc_WHO_J)^Country(?Germany)^has_PM2.5_air_pollution,_population_exposed_to_levels_exceeding_WHO_guideline_value(%of_total)(?Germany,?PM2.5_air_pollution_exc_WHO_G)^swrlb:lessThanOrEqual(?PM2.5_air_pollution_exc_WHO_J,?PM2.5_air_pollution_exc_WHO_G)-> has_less_PM2.5_air_pollution,_population_exposed_to_levels_exceeding_WHO_guideline_value(%of_total)(?Japan,true)
- Country(?Japan)^has_Population_density(people_per_sq._km_of_land_area)(?Japan,?population_dens_J)^Country(?Germany)^has_Population_density(people_per_sq._km_of_land_area)(?Germany,?population_dens_J)^swrlb:greaterThanOrEqual(,?population_dens_J,?population_dens_G)-> has_greater_Population_density(people_per_sq._km_of_land_area)(?Japan,true)
- Country(?Japan)^has_Population_in_largest_city(?Japan,?population_largest_city_J)^Country(?Germany)^has_Population_in_largest_city(?Germany,?population_largest_city_G)^swrlb:greaterThanOrEqual(?population_largest_city_J,?population_largest_city_G)-> has_greater_Population_in_largest_city(?Japan,true)
- Country(?Japan)^has_Population_in_urban_agglomerations_of_more_than1million(?Japan,?population_urban_aggl_1million_J)^Country(?Germany)^

has_Population_in_urban_agglomerations_of_more_than1million(?Germany,?population_urban_aggl_1million_G)^swrlb:greaterThanOrEqual(?population_urban_aggl_1million_J,?population_urban_aggl_1million_G)->has_greater_Population_in_urban_agglomerations_of_more_than1million(?Japan,true)

- Country(?Japan)^has_Population_in_urban_agglomerations_of_more_than1million(%of_total_population)(?Japan,?population_urban_aggl_1million_percentage_J)^Country(?Germany)^has_Population_in_urban_agglomerations_of_more_than1million(%of_total_population)(?Germany,?population_urban_aggl_1million_percentage_G)^swrlb:greaterThanOrEqual(?population_urban_aggl_1million_percentage_J,?population_urban_aggl_1million_percentage_G)->has_greater_Population_in_urban_agglomerations_of_more_than1million(%of_total_population)(?Japan,true)
- Country(?Japan)^has_Population_living_in_slums(%of_urban_population)(?Japan,?population_slums_urb_J)^Country(?Germany)^has_Population_living_in_slums(%of_urban_population)(?Germany,?population_slums_urb_G)^swrlb:lessThanOrEqual(?population_slums_urb_J,?population_slums_urb_G)->has_less_Population_living_in_slums(%of_urban_population)(?Japan,true)
- Country(?Japan)^has_Pump_price_for_diesel_fuel(US$_per_liter)(?Japan,?pump_price_diesel_US$_J)^Country(?Germany)^has_Pump_price_for_diesel_fuel(US$_per_liter)(?Germany,?pump_price_diesel_US$_G)^swrlb:greaterThanOrEqual(?pump_price_diesel_US$_J,?pump_price_diesel_US$_G)->has_greater_Pump_price_for_diesel_fuel(US$_per_liter)(?Japan,true)
- Country(?Japan)^has_Pump_price_for_gasoline(US$_per_liter)(?Japan,?pump_price_gas_US$_J)^Country(?Germany)^has_Pump_price_for_gasoline(US$_per_liter)(?Germany,?pump_price_gas_US$_G)^swrlb:greaterThanOrEqual(?pump_price_gas_US$_J,?pump_price_gas_US$_G)->has_greater_Pump_price_for_gas_fuel(US$_per_liter)(?Japan,true)
- Country(?Japan)^has_Urban_land_area(sq.km)(?Japan,?urban_land_area_sq_km_J)^Country(?Germany)^has_Urban_land_area(sq.km)(?Germany,?urban_land_area_sq_km_G)^swrlb:greaterThanOrEqual(?urban_land_area_sq_km_J,?urban_land_area_sq_km_G)->has_more_Urban_land_area(sq.km)(?Japan,true)
- Country(?Japan)^has_Urban_land_area_where_elevation_is_below5meters(%of_total_land_area)(?Japan,?urban_land_area_elev_below5m_per_J)^Country(?Germany)^has_Urban_land_area_where_elevation_is_below5meters(%of_total_land_area)(?Germany,?urban_land_area_elev_below5m_per_G)^swrlb:greaterThanOrEqual(?urban_land_area_elev_below5m_per_J,?urban_land_area_elev_below5m_per_G)->has_more_Urban_land_area_where_elevation_is_below5meters(%of_total_land_area)(?Japan,true)
- Country(?Japan)^has_Urban_land_area_where_elevation_is_below5meters(sq_km)(?Japan,?urban_land_area_elev_below5m_sq_km_J)^Country(?Germany

)^has_Urban_land_area_where_elevation_is_below5meters(sq_km)(?Germany,?urban_land_area_elev_below5m_sq_km_G)^swrlb:greaterThanOrEqual(?urban_land_area_elev_below5m_sq_km_J,?urban_land_area_elev_below5m_sq_km_G)-> has_more_Urban_land_area_where_elevation_is_below5meters(sq_km)(?Japan,true)

- Country(?Japan)^has_Urban_population(?Japan,?urban_population_J)^Country(?Germany)^has_Urban_population(?Germany,?urban_population_G)^swrlb:greaterThanOrEqual(?urban_population_J,?urban_population_G)-> has_more_Urban_population(?Japan,true)
- Country(?Japan)^has_Urban_population(%of_total)(?Japan,?urban_population_per_J)^Country(?Germany)^has_Urban_population(%of_total)(?Germany,?urban_population_per_G)^swrlb:greaterThanOrEqual(?urban_population_per_J,?urban_population_per_G)-> has_more_Urban_population(%of_total)(?Japan,true)
- Country(?Japan)^has_Urban_population_growth(annual%)(?Japan,?urban_population_growth_annual_per_J)^Country(?Germany)^has_Urban_population_growth(annual%)(?Germany,?urban_population_growth_annual_per_G)^swrlb:greaterThanOrEqual(?urban_population_growth_annual_per_J,?urban_population_growth_annual_per_G)-> has_more_Urban_population_growth(annual%)(?Japan,true)
- Country(?Japan)^has_Urban_population_living_in_areas_where_elevation_is_below5meters(%of_total_population)(?Japan,?urban_population_living_in_areas_elev_below5meters_per_J)^Country(?Germany)^has_Urban_population_living_in_areas_where_elevation_is_below5meters(%of_total_population)(?Germany,?urban_population_living_in_areas_elev_below5meters_per_G)^swrlb:lessThanOrEqual(?urban_population_living_in_areas_elev_below5meters_per_J,?urban_population_living_in_areas_elev_below5meters_per_G)-> has_less_Urban_population_living_in_areas_where_elevation_is_below5meters(%of_total_population)(?Japan,true)
- Country(?Japan)^has_Urban_poverty_gap_at_national_poverty_lines(%)(?Japan,?urban_poverty_gap_J)^Country(?Germany)^has_Urban_poverty_gap_at_national_poverty_lines(%)(?Germany,?urban_poverty_gap_G)^swrlb:lessThanOrEqual(?urban_poverty_gap_J,?urban_poverty_gap_G)-> has_less_Urban_poverty_gap_at_national_poverty_lines(%)(?Japan,true)
- Country(?Japan)^has_Urban_poverty_headcount_ratio_at_national_poverty_lines(%of_urban_population)(?Japan,?urban_poverty_headcount_J)^Country(?Germany)^has_Urban_poverty_headcount_ratio_at_national_poverty_lines(%of_urban_population)(?Germany,?urban_poverty_headcount_G)^swrlb:lessThanOrEqual(?urban_poverty_headcount_J,?urban_poverty_headcount_G)-> has_less_Urban_poverty_headcount_ratio_at_national_poverty_lines(%of_urban_population)(?Japan,true)

- has_greater_Access_to_electricity,_urban(%of_urban_population)(?Japan,true)^has_less_Mortality_caused_by_road_traffic_injury(per_100,000_people)(?Japan,true)^has_less_PM2.5_air_pollution,mean_annual_exposure(micrograms_per_cubic_meter)(?Japan,true)^has_less_PM2.5_air_pollution,_population_exposed_to_levels_exceeding_WHO_guideline_value(%of_total)(?Japan,true)^has_greater_Population_density(people_per_sq._km_of_land_area)(?Japan,true)^has_greater_Population_in_largest_city(?Japan,true)^has_greater_Population_in_urban_agglomerations_of_more_than1million(?Japan,true)^has_greater_Population_in_urban_agglomerations_of_more_than1million(%of_total_population)(?Japan,true)^has_less_Population_living_in_slums(%of_urban_population)(?Japan,true)^has_greater_Pump_price_for_diesel_fuel(US$_per_liter)(?Japan,true)^has_greater_Pump_price_for_gas_fuel(US$_per_liter)(?Japan,true)^has_more_Urban_land_area(sq.km)(?Japan,true)^has_more_Urban_land_area_where_elevation_is_below5meters(%of_total_land_area)(?Japan,true)^has_more_Urban_land_area_where_elevation_is_below5meters(sq_km)(?Japan,true)^has_more_Urban_population(?Japan,true)^has_more_Urban_population(%of_total)(?Japan,true)^has_more_Urban_population_growth(annual%)(?Japan,true)^has_less_Urban_population_living_in_areas_where_elevation_is_below5meters(%of_total_population)(?Japan,true)^has_less_Urban_poverty_gap_at_national_poverty_lines(%)(?Japan,true)^has_less_Urban_poverty_headcount_ratio_at_national_poverty_lines(%of_urban_population)(?Japan,true)-> Higher_Rank_in_Urban_Development(?Japan)

The predefined queries endpoint facilitates additional examination of the data set. A query seeks for data that match the defined patterns. Queries have been constructed to answer questions like “Which countries have the greatest development growth?” producing a set of results (countries) and their scores on the development indicators. SPARQL predefined queries ease the decision makers to explore the dataset even if they are not familiar with Semantic Web technologies.

Table 22 – Excerpt SPQs and their SPARQL equivalent

SPQ	**SPARQL**

Give me all the indicators of the dimension Gender.	`SELECT ?indicator`
	`WHERE`
	`{`
	`   ?indicator belongs_to ?dimension;`
	`       ?dimension=”Gender”`
	`}`

Show the countries that were ranked at the top 7 ranking positions.	`SELECT ?country`
	`WHERE`
	`{`
	`   ?country ranked ?position`
	`}LIMIT 7`

Give me all the profiles of the world development.	`SELECT ?profile`
	`WHERE`
	`{`
	`   ?profile belong_to "WDI"`
	`}`

Retrieve the 2 countries that have better performance at the dimension Social Protection & Labor.	`SELECT ?country WHERE { ?country ranked_SPL ?position; ?position<3 }`

4.6.2.5 The WDI-IS (World Development Indicators-Information System)

The WDI-IS information system is another instance of the MOBVR system on the world development context. Like the AcademIS information system, the WDI information system involves great complexity. However, the system is designed in such a way that the decision maker does not perceive the complexity and is easily guided to informed decisions. Especially in the example of WDI-IS, the volumes of both data and the constituents of the ranking (i.e. criteria, indicators) are vast, so the diminishment of the complexity is even more necessary. The homepage of the WDI-IS provides an overview of the basic concepts (i.e. countries, continents, indicators, profiles, etc.) of the information system. By selecting one of the above options (for instance the countries), the decision maker is redirected to a list of all the available records of this kind (for example all the countries in the WDI-IS). Each record is further described in its dedicated webpage, for instance information about a selected country. The WDI-IS web interface gives access to the results of the MOBVR algorithm applied in the world development progress dataset, which is depicted by the Comparative Ranking of the countries. Comparative Ranking of the alternatives is a visual analytics component implemented with Parallel Coordinates visualization (Figure 29). A performance fingerprint is created for each world development progress profile.

In order to construct the performance fingerprints of a specific country in a specified area of interest, we assess the country's performance on the constituents of that area. So, as far as it concerns the performance fingerprints of the profiles, they are composed by the dimensions of the profile. In the case of WDI paradigm, four profiles have emerged, namely, the economic, the environmental, the progress and the social profile. The economic profile is composed by the aid effectiveness, the economy & growth, the energy & mining, the external debt, the infrastructure, the poverty, the private sector, the public sector and the trade. The climate, the energy & mining and the environment synthesize the environmental profile. The progress profile consists of the following dimensions: Agriculture & rural development, education, infrastructure, science & technology, the social development and the urban development. The social profile is composed of gender, health, poverty, social development and social protection & labor.

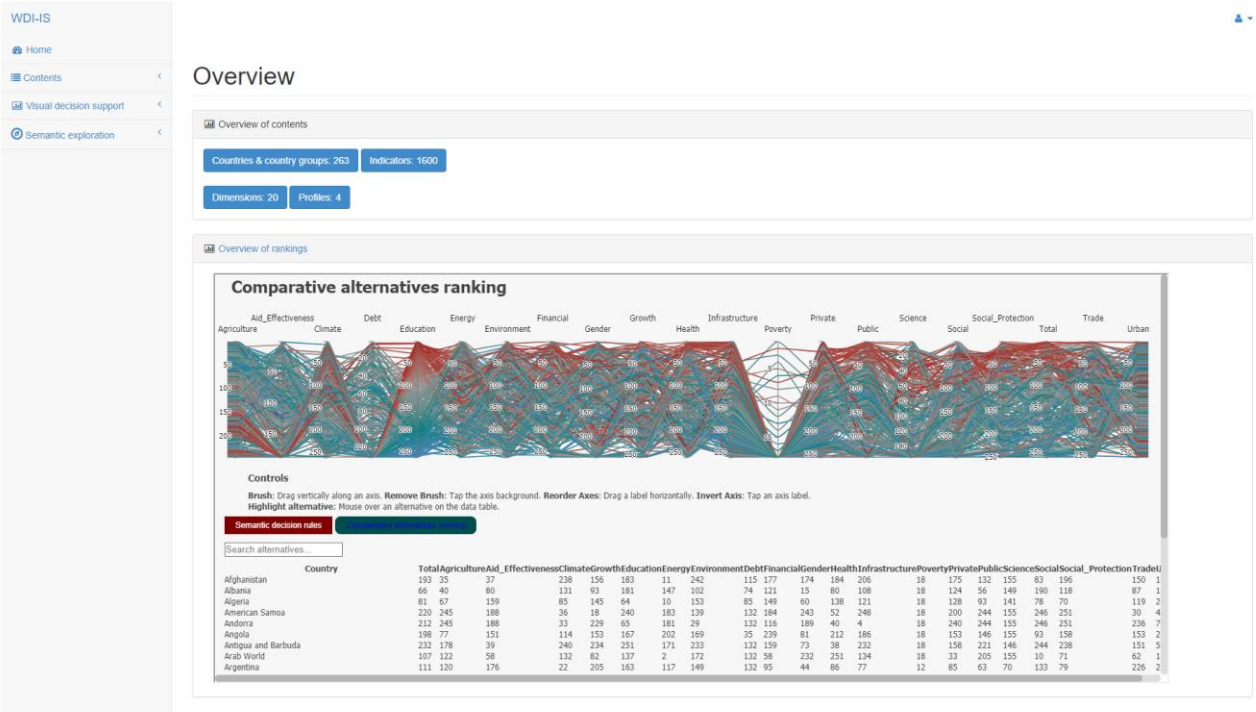


Figure 29 – Comparative ranking of countries based on the results of the ontology-based ELECTRE III

The performance fingerprint of a dimension is assembled of its criteria, grouped in categories. In the WDI case study, there are 20 dimension-centered performance fingerprints. The performance fingerprint of the Agriculture and rural development has five groups of criteria: the equipment, the land, the production, the population and the poverty. The grants, the official development assistance, the education, the mortality, the health and the economy constitute the aid effectiveness performance fingerprint. The performance fingerprint of the Climate change dimension consists of the following groups the land, the power, the emissions, the population, the freshwater withdrawals, the renewable energy and the economy. The economy & growth entails six groups: the exports, the imports, the debt & loans, the official development aid, the financial, the production. The literacy rate, the duration, the enrollment, the teachers, the population, the expenditure, the completion rate, the educational attainment, the repeaters, the out of school and the unemployment are included in the performance fingerprint of the education dimension. The energy and mining comprises the subsequent groups: the renewable & alternative power, the exports, the imports, the energy use and the energy access. The groups inherent to the performance fingerprint of the dimension environment are the following: the equipment, the land, the energy, the production, the renewable, the threatened, the emissions, the population, the energy rents, the protected areas, and the water. The external debt fingerprint encompasses the loans-debt group, the economy, the production group, the official development aid, the trade, the savings and reserves, the GDP and the consumption. The financial sector involves five groups of criteria, namely the economic, the market capitalization, the stocks, the banks and finally the transactions. The performance fingerprint of the dimension gender is composed of: the equity, the social, the education (women), the education (men), the legislation, the health (women), the health (men), the financial (women) and the financial (men). For the dimension health, the groups apparent to the respective performance fingerprint are the risks, the mortality, the life, the diseases, the expenditure, the population, the health infrastructures and the social. The energy, the services, the water, the transport and the fuel are involved in the performance fingerprint of the dimension infrastructure. The performance fingerprint of poverty contains the following groups of criteria: the financial, the poverty, the income share held by highest 20%, the income share held by highest 10%, the income share held by second 20%, the income share held by third 20%, the income share held by fourth 20%, the income share held by lowest 10% and the income share held by lowest 20%. The ease of business, the exports, the imports, the international tourism, the investment, the taxes and the legislation, the tariff rate, the logistics and the financial are the groups of criteria for the private sector's performance fingerprint, while the financial group, the taxes, the expenses, the human capital, the military and the social are the groups of the performance fingerprint of the dimension public sector. Science and technology includes the following groups: intellectual property, patents & trademarks, research and technology in its performance fingerprint, whereas social development contains the subsequent groups: education, health, employment and refugee. The performance fingerprint of the dimension social protection and labor comprises the groups of criteria: protection, social, coverage, employment, labor force and unemployment. The performance fingerprint of the dimension trade is built around the following groups: ease of trade, exports, imports, taxes & legislation, logistics, tariff rate, international tourism, investment and financial. The urban development involves the pollution, the population, the mortality and the poverty groups.

4.6.2.6 Usage scenarios

In this section, seven indicative usage scenarios of the WDI-IS system are described. Each usage scenario concerns a different group of stakeholders and explicates the way that WDI-IS system facilitates their needs. A comparison of the necessary activities to perform a scenario before and after the system is also presented.

- **Ministries:**

Scenario: The employees of a ministry require information about certain indexes of development growth.

The implicated MOBVR component: The WDI-IS web interface and the country's fingerprint.

Before the system: The employees of the ministry search the indexes that interest them in the website of World Bank for the World Development Indicators. The aforementioned website allows them to acquire information about one indicator for a selected period. Moreover, they retrieve various reports authored by the World Bank. The information is scattered in many different sources (i.e. the individual webpages of development indicators of World Bank and its reports) and the users should spend significant amount of time and effort to accumulate all the related information and make their deductions.

After the system: The employees of the ministry access the WDI-IS of the MOBVR system. They can inspect the country's fingerprint which displays the development indexes categorized in profiles. Hence, the employees of the ministry do not have to browse each indicator separately. However, they can retrieve more information when it is needed. They can examine the webpages of the WDI-IS for the selected indexes of development. The whole information is available through the web interface. So, the examination of the information and the decision making process is becoming easier and less time-consuming.

- **Public agencies:**

Scenario: An employee of a public agency needs information about the development progress of the country and its neighbors to include it in a report.

The implicated MOBVR component: The WDI-IS web interface, the countries' comparative ranking and the country's fingerprint.

Before the system: The employee of the public agency browses the World Bank's website about the World Development Indicators and searches each country's webpage. The webpage of each country contains information about its development. The employee should then collate the information and include the required pieces of information in his/her report.

After the system: The employee of the public agency accesses the WDI-IS of the MOBVR system and selects the comparative ranking of the countries choosing the countries in which he/she is interested. The selected countries are displayed in the comparative ranking, allowing the user to easily comprehend which country has better performance on the selected indicator. The user can then browse each country separate webpage in the web interface and fingerprint to have a better understanding of its performance.

- **Banks:**

Scenario: The employees of a bank need to assess the credit rating of a country against other countries.

The implicated MOBVR component: The WDI-IS web interface and the countries' comparative ranking.

Before the system: The bank employees browse the financial indicators that are provided by the World Development Indicators interface of the World Bank. Each indicator is browsed separately.

After the system: The bank employees select the countries' comparative ranking to overview the development status of the countries, as well as to compare their statuses.

Moreover, they can browse the individual webpages of the countries in the WDI-IS to acquire more information about their development progress.

- **Organizations:**

Scenario: An organization needs to go global and searches for a country in which to be expanded.

The implicated MOBVR component: The countries' comparative ranking.

Before the system: The organization can either access each indicator or each country individually and then compares them in order to decide in which country it will be expanded based on the country's development progress.

After the system: The organization accesses the countries' comparative ranking and brushes the axes (i.e. dimensions) financial sector, economic growth and private sector for the desired values. The alternatives that are displayed are those that suffice the given requirements.

- **European Commission:**

Scenario: A member of European Commission requires information regarding the development indicators of the country-members of European Union.

The implicated MOBVR component: The WDI-IS web interface, the country' fingerprint and the countries' comparative ranking.

Before the system: The member of the European Commission accesses the development indicators for each country-member of European Union. Each development indicator can be browsed separately.

After the system: The member of the European Commission selects the countries' comparative ranking and chooses to display only the members of the European Commission. Then, he/she inspects the overview of the countries' performances. Further details on the countries' performance are available in each country's webpage and fingerprint.

- **Policy makers:**

Scenario: A policy maker wants to deduce about the status of a country in order to take corrective action.

The implicated MOBVR component: The WDI-IS web interface and the country's fingerprint.

Before the system: The policy maker accesses the development indicators of the country, one indicator at time and inspects how each indicator has changed over time. Then, the policy maker makes decisions based on the presented data.

After the system: The policy maker browse the country's webpage in the web interface of the WDI-IS and inspects the country's development progress over the years in the involved indicators. Then, the policy maker accesses the fingerprint of the country in the implicated profiles.

- **Public:**

Scenario: A resident of a country wants to inspect the country's growth in the past years.

The implicated MOBVR component: The WDI-IS web interface and the country's fingerprint.

Before the system: The resident of the country retrieves the development indicators of the country and examines its growth over the past years.

After the system: The resident selects the country's fingerprint and examines the way that the performance of the country has changed over the years. He/she then accesses the webpage of the country in order to retrieve more information.

4.7 Statistical analysis of the contents of knowledge bases

A thorough statistical analysis of the two knowledge bases of the presented case studies is apposed, in order to understand the size of the knowledge bases and the inherent relations among the data. From the two knowledge base (i.e. AcademIS and

WDI), we extract all the entity-entity relations (ree) and all the entity-literal relations (rel). The statistics of the knowledge bases are presented in Table 23. In the first column the amount of relations is presented, while in the second column the number of relations with less or equal than 50 triples is filtered. Finally, in the last column the total amount of triples in the knowledge bases is displayed.

Table 23 – Statistics of the knowledge bases of the case studies, amount of relations, number of relations with less or equal than 50 triples and total amount of triples

	#relations		**≥50triples**		**#triples**
	$\mathbf{r_{ee}}$	$\mathbf{r_{el}}$	$\mathbf{r_{ee}}$	$\mathbf{r_{el}}$	
AcademIS	250	194	36	45	5689
WDI	25030	16890	215	369	48098

Table 24 – Amount of #owl:sameAs links in the knowledge bases

KB	**AcademIS-MOBVR**	**WDI-MOBVR**
#owl:sameAs	215	20509

Table 25 – Percentage of queries using the different SPARQL features

	KB	
	AcademIS	**WDI**
UNION	14	9.3
OPTIONAL	23	18
DISTINCT	5.5	13
FILTER	6.9	7
REGEX	12	21.2
FROM	17.6	10
LIMIT	4	5.6
JOIN	7	6
SERVICE	4.8	2.5
SUB-QUERY	5.2	7.4
Overall	100%	100%

In table 24, the owl:sameAs relationships between the knowledge bases are presented. More specifically, the owl:sameAs links between the datasets AcademIS and its subset MOBVR, and WDI and its subset MOBVR are described. The percentages of the queries that utilize the different SPARQL features are displayed in table 25.

4.8 Cross-case analysis

Cross-case analysis (or synthesis) is a qualitative technique for analyzing case study evidence, when two or more case studies have been conducted. In the cross-case analysis, each case study is handled as an independent study and seeks for patterns across the case study with meta-matrices and word tables that present qualitative data according to a uniform framework. The similarities and the differences between the involved case studies are also examined. It consists of three steps: i) data reduction, ii) data display and iii) conclusion drawing/verification [267]. Thus, the cross-case synthesis leads to interpretations across the case studies.

To further explain the issues of applying the MOBVR methodology to a domain, a cross case analysis of the case studies is conducted, in which the two case studies are contrasted and analyzed. First an exploration of cases similarities and differences is presented, followed by the identification of patterns across the case studies. The cross case analysis involves the examination of the two case studies and the identification of their similarities, differences and the patterns among them. The cross-case analysis involves three steps. The first step corresponds to the data reduction, in which the results of the case studies are handled, the second step is the data display, in which the presentation of the information in a structured and compressed manner that leads to the third step, which is the conclusion drawing (or verification). Therefore, the most significant features of the conducted case studies are examined in table 26, whereas complementary features of the case studies are inspected in tables 27 to 30. To elaborate, in table 26, the word table reveals the ranking patterns across the ranking domains of the two case studies and the characteristics of each ranking. The table 27 depicts the multidimensionality patterns of the two case studies, while the visual analytics patterns are presented in the table 28. The decision making patterns word table is displayed in the table 29, whereas the table 30 portrays the semantic organization patterns of the involved case studies. From the presented word tables result to the identification of the case similarities and differences, as well as the patterns across the case studies that will be pinpointed in the following section.

Table 26 – Ranking patterns word table (2 ranking domains and their characteristics)

Ranking domains	**Characteristics of ranking**
AcademIS	Multidimensional ranking on the performance of academic units. The academic units are assessed based on the various indicators of academic performance, such as education, research and collaborations. The rankings concern many stakeholders with different backgrounds and abilities. The ranking results are available under open license.
WDI	Multidimensional ranking on the development progress of countries or regions. The countries or regions are evaluated according to their development progress on a set of indicators concerning financial, environmental, social and development aspects. The WDI rankings also implicate numerous stakeholders with different backgrounds and abilities. The ranking results are available under open license.

Table 27 – Patterns of multidimensionality word table (2 multidimensional domains and their characteristics)

Multidimensional domains	**Characteristics of multidimensionality**
AcademIS	A moderate amount of dimensions, with many criteria. The dimensions can also synthesize a small number of profiles.
WDI	A large amount of dimensions with an enormous amount of criteria. Profiles can accrue from the combination of dimensions.

Table 28 – Visual analytics patterns word table (2 case study and their characteristics)

Case studies	**Characteristics of visual analytics**
AcademIS	The visual analytics components in the AcademIS case study are the comparative ranking, which contains a moderate amount of alternatives and a small amount of dimensions.

WDI	The WDI case study is also centered on two visual analytics components to present the ranking results. The first is the comparative ranking of the entities, which in the case of WDI visualize a vast amount of alternatives' performance on a large amount of dimensions. The second one is the performance fingerprint of an alternative on a selected profile.

Table 29 – Decision making patterns word table (2 case study and their characteristics)

Case studies	**Characteristics of decision making**
AcademIS	The AcademIS case study implicates decision making on multidimensional setting. The case study involves ranking based not only on criteria but also on dimensions. Adding an extra level of computation in the multiple criteria decision making process.
WDI	The decision making process in the WDI case study is also characterized by multidimensionality and relies on evaluating the domain on criteria and dimensions.

Table 30 – Patterns on the organization of the data word table (the 2 case study and their characteristics of organization of the data)

Case studies	**Characteristics of organization of the data**
AcademIS	The concepts of the AcademIS ontology are endowed with rich semantics and many relationships over the data that reveal the complexity and the interactivity between the concepts of the domain.
WDI	The WDI concepts are characterized by a small amount of relationships that represent the associations between the indicators and their characteristics.

4.8.1 Cases similarities

Several of the case similarities that were identified are the multidimensionality, the existence of multiple stakeholders with diverse background and the presence of profiles within the domains of the case studies. Both the case studies are characterized by *multidimensionality*, which allows the MOBVR methodology to be applied to them. Multidimensional domains comprise manifold criteria and dimensions, into which the criteria are fallen. In both case studies, the rankings and the web interface should be able to support decision making conducted by *multiple stakeholders with diverse background and abilities*. Therefore, the whole system in both cases should facilitate even the novice users, concealing the underlying complexity of the domains, but maintaining the same level of detail as far as it concerns the information. The dimensions of the domains of both case studies can be combined into *profiles* that manifest the various aims and objectives that are present in the domain.

The similarities that have been indicated in the case studies mirror the basic features of the framework. To elaborate, the framework addresses ranking of multidimensional domains that facilitate the decision making of diverse user groups of stakeholders and allows the identification and the support of the different aspects of a domain.

4.8.2 Cases differences

Apart from the identified similarities the cross-case analysis denoted several differences among the two case studies, including the domain model design, the amount of the dimensions, criteria and alternatives of the case studies. To elaborate, regarding the *domain models* of the two case studies, in the first case study there are more relationships between the data, resulting to a more complete representation of the interaction and characteristics of the involved actors of the domain, while the second case study is focused on providing evaluation-oriented data, which have as a direct consequence less concepts and interaction among them, but the presence of more characteristics of the existing concepts. The *amount of dimensions* within a domain differs from case study to case study. To be more precise, in the first case study there is a small amount of dimensions, while in the second case study there are many dimensions. Another difference between the case studies is the *amount of criteria*, which in the first case are manifold, while in second case study their number is enormous. The *amount of alternatives* also diverges between the case studies. While in the first case study there is a small amount of alternatives, in the second case study there is a large number of alternatives.

The differences between the case studies denote that the proposed solution can host domains which consist of a wide range of dimensions, a wide range of criteria, and a wide range of alternatives. Moreover, the proposed framework can facilitate the ranking of various domains regardless of the structure of the domain model. Therefore, the MOBVR framework is applicable in domains regardless of its characteristics (e.g. dimensions, criteria, alternatives and their amount, as well as the structure of the information).

4.8.3 Patterns across the cases

During the cross-case analysis some issues that can hinder the smooth decision making process. In this section, these issues will be discussed and possible solutions will be also proposed. The identified patterns across the case studies include the existence of contradictory criteria, the lack of information about certain criteria, the inability of the involved stakeholder to determine the weights of the criteria and the dimensions, as well as the presence of proprietary and closed information within the dataset.

- In multidimensional ranking, multiple criteria and dimensions contribute to the final outcome. As a result, the presence of *contradictory criteria* is inevitable.

  Solution: The selected algorithm in the MOBVR framework is ELECTRE III. The ELECTRE family and the MCDA algorithms in general are occupied with proposing solutions in multiple and even contradicting criteria.

- The rankings are designed to capture all the important indicators that affect the performance of the specific entity. However, sometimes there is not any information concerning one or more indicators. *The lack of information about certain criteria* of the rankings impedes the computation of the ranking results on the dimensions and consequently the overall rankings. In other cases, information about selected criteria may be available only for specific periods, while information about other periods may be lacking.

  Solution: One possible solution can be the withdrawal of this criterion or these criteria from the rankings and the implementation of the ranking process only on the criteria for which there is the required information. When the information about certain criterion / criteria is available only for a specific time, this criterion or these criteria should also be removed from the rankings or alternatively only the data for the existing time periods should be used, but in any case, the information should be available in the web interface and accessible to the decision maker, so as to have the bigger picture about the rankings' object.

- As mentioned before, there are multiple stakeholders that may have different backgrounds and diverse abilities. Hence, a problem that may arise is the *inability of the involved stakeholder to determine the weights of the criteria and the dimensions, as well as the thresholds (preference, indifference and veto).* More specifically, the novice stakeholders may feel overwhelmed and confused by the process of defining the large amounts of thresholds required by the process and the weights of the multiple criteria and the dimensions. Furthermore, these stakeholders may not be equipped to delineate weights according to each factor's significance due to ignorance about the impact of each indicator to the overall domain.

  <u>Solution:</u> A proposition about resolving the lack of ability of certain stakeholders to assign weights to the criteria and the dimension can be the existence of predefined weights. The predefined weights can be altered by the expert stakeholders that are familiar with the role that each indicator play in the rankings and that can interact more fluently with the system.

- Although, the MOBVR framework relies on open data, in several occurrences, a part of the information on which the rankings are based, may be closed and its sharing may be prohibited, making the reproducibility of the rankings impossible. Nevertheless, this information may be of vital importance for the rankings, making necessary the inclusion of the *proprietary and closed information within the dataset.*

  <u>Solution:</u> A related solution can be the utilization of such information in the rankings and its non-disclosure in the re-usability stage of the framework. In case that the information concerns the name of alternatives, the use of name such as Alternative_1, Faculty_1, etc. is proposed. The same proposition stands in case of

names of actors within the indicators (i.e. the Academic_1 that is_part_of Faculty_1 has authored 10 papers during 2017). However, if the information is about criteria (i.e. the value of the criterion land area in sqkm and the value of the criterion protected land in sqkm) is proprietary and closed, then it should be used while computing the ranking order of the alternatives and it should be omitted in the shared information. Nonetheless, in order to enable the reproducibility of the results, a summative output considering all the proprietary and closed information should be available, which would not declare the initial values of criteria, but will assist the accountability and the verification of the rankings.

4.9 Summary and conclusion

As derived from the previous sections of this chapter, the proposed framework can host even large datasets, without imposing any delay on the process and without any reduction in the quality of the results. The presented case studies had different conceptualization approaches on their domains, even though they were both hosted effectively by the MOBVR framework.

Chapter 5 . Conclusion and perspectives

The thesis is focused on the development of a methodology for the ranking of multidimensional data and employs a visual-aided ontology-based MCDM approach. The ranking problematic concerns a wide spectrum of problems, from HEI ranking to product ranking, and in general every problem that requires an ordered ranked of entities and as a result the application domains range as well. Due to the variety of the fields that this approach can be applied to, the incorporation of the ontologies is crucial, since they boost the transition of the system between different domains. Nevertheless, the use of ontologies is not limited to providing a more effortless shift between domains, but rather assists and affects the foundations of the decision support process itself. To be more precise, the ontology is integrated to the very core of the MCDM ranking approach and offers the means to represent and capture the concepts related to that specific process, including the various profiles, the dimensions, the criteria and the weights. In that way, the MCDM ranking approach is enhanced in terms of time needed to be completed, of robustness of the method and of expression of the process, which is undergone in a versatile and concrete manner.

Multidimensional ranking pertains to the classification of vast amounts of information and the presentation of the ranking results to the decision maker. Although the ranking approaches ease the stakeholders to conclude to a solution to their problem, the majority of them offer only textual representation of their findings, or visualization. However, the human perceptual capacity is quite narrow when it regards to text, but it is amplified in case of visual representation of the information. Visual analytics have the capacity to host and handle the presentation of voluminous datasets in a way that the information can be conceived more easily. As a direct consequence, by integrating visual analytics in the proposed approach, the overall decision making time is enhanced, the stakeholder is eased to decide, as the ranking results are presented in a more effective and productive way that is easier understandable. Hence, the approach employs the advantages of visual analytics and ontologies to the benefit of the multidimensional ranking.

In this thesis ways in which multidimensional data can be used in MCDM systems assisted by visual analytics and ontologies are sought out, as well as how such a system can ameliorate the decision making process and lead to informed and insightful decisions.

5.1 Structure

This chapter is structured as follows: the first section corresponds to the introduction of the conclusion and perspectives chapter, and then there is the structure of this chapter, followed by the findings of the study. An analysis of the theoretical implications is also outlined at the fourth section, while in the fifth section the policy implications are described. Furthermore, the limitations of the study are presented in section six, along with the recommendations for future research, which is described in the seventh section. Last but not least, in section eight of this chapter provides the summary and the conclusion.

5.2 Findings

The main findings of the dissertation study were presented within the following chapters of the thesis: the *Chapter 3 – Methodology* and *Chapter 4 – Design and implementation*. In this section, the main research questions (introduced in chapter 1) posed by this research will be answered with the use of empirical findings.

- ***RQ1: How can a visual-aided ontology-based MCDM system facilitate informed and insightful decisions on multidimensional data?***

DSSs and therefore MCDM systems ought to act in similar manner with human consultants, by supporting [81, 82] the stakeholders through the whole decision making process. Thus, the decision makers should have a clear view in terms of comprehending, communicating and forming the problem [81]. The proposed solution introduces the following benefits into the multiple criteria decision support process:

a. *Amplified perceptual capacity of the system's end user:* Such a system reduces decisively the volume of the data to be presented by replacing it or complementing it with straightforward visual representations [83] and as a direct consequence, it restrains the decision makers from the information overload. The MOBVR framework, based on the alternatives' comparative ranking and the entity's performance fingerprint visual representations, ultimately leads to informed and insightful decisions.
b. *Revelation of information that otherwise would not be visible:* Visualizations, and in this case the alternatives' comparative ranking and the entity's performance fingerprint, reveal patterns and information that would be difficult to perceive [83, 84], enable hypothesis formation [84], a fact that supports and enhance the decision making process. Additionally, semantic based exploration of the data through the predefined SPARQL queries unveils information about the alternatives that are ranked, as well as the whole dataset.
c. *Easier multidimensional comparison between the subjects:* Due to the visualization of the data (the alternatives' comparative ranking and the entity's performance fingerprint), the information presented is easier comprehended and compared by the stakeholders [83]. It is easy to identify the candidate with the best score at all the variables and it is easy to realize what alternative is better compared to others.
d. *Improved interoperability:* Due to the utilization of ontologies (the MOBVR ontology and its individual parts), it increases the interoperability [85, 86] levels of both i) the data and ii) the information system, by enabling and boosting their independency, their transferability and their reuse. As a result, the data can be used in other information systems and for different purposes. Also, the information system can process and support the incorporation of different domains with the change of the domain ontology, which is a part of the MOBVR ontology.
e. *Provision of foundation and solid structure for the MCDM component:* In the MOBVR system, the creation of a MCDM-ready environment and integration of the multiple criteria decision support process takes place that prepares the data for the process with the utilization of ontologies [87, 88] and ameliorates the examination of the problem and the corresponding data by the decision

maker with the use of visualizations [89, 90] and more specifically visual analytics [91].

- ***RQ1.1: How can visual analytics be implemented and integrated in a MCDM system to aid the DM process?***

a. *Presentation of the MCDM findings in an appealing manner:* The visual analytics present the information in an easier conceivable and more comprehensible way, by putting the data into context and showing the information in a more appealing way [92, 93]. To elaborate, the MOBVR system utilizes the alternatives' comparative ranking to display the outputs of the multiple criteria process.

b. *By including all the information needed for the final decision, but in the same time avoiding the excess of information:* The system visualizes the information required for the decision making process without showing irrelevant information to the ranking task. The whole information on which the rankings are based is available through the web interface (the AcademIS for the first case study and the WDI-IS for the second case study).

   Moreover, the data is "compressed" through the ability of visualizations to present a large amount of information effectively [17]. Therefore, the end user of the system can access the ranking results in the comparative ranking of the alternatives and the various profiles of each alternative in the entity's performance fingerprint. Further examination of the ranking results, where the alternatives are ranked in the same position, is possible through the SDR (Semantic Decision Rules). Additional exploration of the dataset can be achieved by utilizing the SPQs (Semantic Predefined Queries). Thus, the decision makers can process the presented information and make perceptive decisions.

c. *By reducing the cognitive burden of information overload:* With the use of visualizations in the MOBVR system, the cognitive load is minimized [83] and the visualized information is easier processible and understandable than raw data [94].

- ***RQ1.2: How can ontologies be utilized to facilitate a MCDM ranking method regardless the domain?***

a. *Captures all the crucial elements of the MCDM approach:* With the use of this method, we verify that the prerequisites of the MCDM exist and that they are in compatible format with that component. To be precise, it ensures the multidimensional character of the domain under consideration, the type of the criteria and the kind of the dimensions.

   The ontology preprocesses the information needed for the MCDM and transforms it in such a way that it will ease the decision support process and the input of the data to the ELECTRE III.

b. *Integrates the ontology at the basis of MCDM:* The ontology creates the necessary background for the multiple criteria decision support by inferring essential information, such as criteria. It also structures and hosts the information required for the evaluation. The ontology is an inseparable piece of the MCDM that functions as a mean to boost the interoperability of the process and its individual components.

c. *Reduces the domain specific information in the MCDM application:* Hence, it promotes the transferability of the data and the adaptability of the system. So, with several minor changes, this methodology can be applied to other domains. The ontology enables the independence of the system and the data, by separating the one from another.

- ***RQ1.3: How can visual analytics and semantic web technologies be combined in order to enhance the user-system interaction?***

a. *Integrating semantic web technologies in visual analytics components:* Visual analytics visualize the semantic web compliant information in both visual components, namely the alternatives' comparative ranking and the entity's performance fingerprint. The visual components offer interaction capabilities, such as filtering, brushing, zooming and details on demand.

b. *Allowing interactions between visual analytics and semantic web components:* This is achieved by integrating a feedback mechanism, which depends on the proposed semantic decision rules incorporated into the ontology in cases when the alternatives are ranked in the same order due to incomparability and indifference. This mechanism is triggered in the before mentioned cases and is facilitated by the interaction capabilities of visual analytics (the alternatives' comparative ranking, or else parallel coordinate plot) to present only the alternatives that created the issue in line with the SDRs in the selected visual analytic component.

- ***RQ1.4: How can we make ranking deductions for multifaceted data irrespective of the context?***

a. *Capturing dimensions, criteria and weights with the use of an ontology:* In order to be able to rank irrespective of the context, all the necessary information for the ranking must be captured, including i) domain specific characteristics, ii) the context to which the ranking is applied, and it should be structured as LOD with the aid of an ontology. In that way, the information is becoming independent from the Information System.

b. *Defocusing the Information System from the domain:* By leaving in the Information System the less domain specific information possible, the information system can easily be modified and adopted in another domain.

- ***RQ2: Which are the prerequisites for an application domain in order to apply to it the Multidimensional Ontology-Based Visual Ranking framework?***

a. *The MOBVR competency check captures the prerequisites imposed by the framework for the domain:* Once the domain passes the MOBVR competency check, it is ready to be processed and assessed by the homonymous system. These requirements: i) inspect the applicability of the methodology and ii) the ELECTRE III to the domain; iii) they also retrieve several important details about the domain. The MOBVR Competency Check and the requirements are described in the section 3.3.4.1 The MOBVR Competency Check.

- ***RQ3: What is the current stage of decision making methods assisted by visual analytics and/or semantic web technologies and what are the research gaps?***

a. *The current stage of decision making methods aided by semantic web technologies:* Both visual analytics and semantic web technologies have been used individually to boost the decision making process and to enable decision makers to reach informed decisions, fewer methods have been implemented in settings where the decisions dictate a multiple criteria approach, while more methods have been implemented in less complex decision making. There are also a few methods that involve decision making, visual analytics (or visualizations) and semantic web technologies. Nevertheless, none of these methods does not support multidimensional decision making.

b. *Research gaps:* Despite the fact that there are a few approaches that combine decision making, visual analytics and semantic web technologies, none of these methods involve a MCDM algorithm, nor are applied in more than one application field.

- ***RQ4: What is the current stage on multidimensional MCDM approaches and what are the research gaps?***

a. *Current stage:* There are a few multiple criteria methods that classify a problem into sub-problems, such as hierarchical ELECTRE III [130] and AHP [131]. Nevertheless, the existing multifaceted MCDM methods consider multiple levels of criteria [130, 131], rather than clustering of the criteria that is considered in our method.

b. *Research gaps:* However, there is not any approach that implicates independent and combinable dimensions, which are composed by groups of criteria. Many benefits can emerge from such an approach, for instance the representation of the most significance aspects of a domain, which indicate its nature and the support of profiling the subdomains of the domain.

The proposed framework builds upon the visual analytics and ontologies to enhance the decision making process, especially in the ranking problematic. It leverages the datasets to allow the decision makers to gain insights, as well as to guide them and support them through the decision making process. Compared to the other methods, it promotes the discoverability of the multidimensional information through the visual analytics and fosters the interoperability of both the data and the Information System, because of the use of ontologies and LOD.

5.3 Theoretical implications

It is of vital importance to reexamine the theoretical information of the intersection of MCDM, visual analytics and semantic web so as to achieve better comprehension of the semantic-enabled visual-assisted multidimensional ranking and how to form a reliable and attainable methodology. According to [282] a DSS system should support the end user in the same manner that a consultant would do. To elaborate, it is ideal to guide the users through the decision making process and to support them in each step. The implications of the MOBVR approach are listed in the subsequent section.

5.3.1 Contribution

The main contributions of the presented approach can be classified in the following categories: contribution to theory, contribution to practice and contribution to research:

- The contribution to theory is the design and the establishment of the theoretical framework of Multidimensional Ontology Based Visual Ranking (MOBVR), which is proposed as a solution to the problem of multidimensional ranking. It constitutes a theoretical foundation for the implementation of a MOBVR system. It proposes a new methodology, as well as the underlying conceptual and theoretical analysis. The MOBVR framework builds on the theories of visual analytics, semantic web, multidimensional ranking and multiple criteria decision making analysis to make feasible a novel ranking methodology. Not only, does it combine the before mentioned theoretical subjects, but also evolves all the stages of the decision support approach and proposes a new MCDM framework.
- The contribution to practice is the formation of a sequence of steps (a framework) that supports the manipulation of the LOD in the context of visual MCDM ranking. The thesis explores the amalgamation of these research areas

and provides the technical background and infrastructures required for such a merge. Furthermore, it utilizes the aforementioned techniques in two independent and distinctive case studies. The first case study was implemented in the academic field, while the other was applied in the world development domain. The thesis describes how the process is altered to comply with the needs, peculiarities and characteristics of each domain, relied on its ontology based structure.

- The contribution to research is the exploration of an interdisciplinary scientific area that encompasses the visual analytics, the decision support systems, and more specifically the MCDM, and the semantic web, as well as their combination in the MOBVR framework.

5.4 Policy implications

Several studies, as well as this dissertation, support that the employment of visual analytics can lead to better understanding of the presented information, especially when the information is multidimensional and complex. This theoretical framework has been applied in the MOBVR prototype as a proof of concept for the visual-aided ontology-based MCDA approach and the way that it can raise the awareness of the decision maker regarding the ranking problem and ameliorate the decision process, reducing both time and effort needed for the completion of an intricate decision making task. Moreover, this approach relieves the programmers of a DM system from the re-programming the whole process, since the system can be modified easier to fit the needs of another domain.

5.5 Limitation of the study

The research has proposed a visual multiple criteria decision making method assisted by a semantic infrastructure and applied in the academia and in the world development setting through the LODification component. Several of the limitations that we have faced are the following:

- Due to the design of the MOBVR methodology, the approach is applicable at multidimensional domains.

- This approach is easier applicable to the evaluation and more specifically the ranking of entities (such as institutions, organizations, individuals, products, etc.).

5.6 Recommendation for future research

The presented visual-aided ontology-based approach is meant to solve multidimensional ranking problems. During this thesis the following recommendations for future research has been emerged:

- First and foremost, there is the need to expand this approach to also cover domains without multidimensional aspects.
- Furthermore, this approach can be further exploited to facilitate ranking purposes other than evaluation.
- It can also be extended to work with looser forms of ontologies, such as vocabularies, lexicons, etc. to be able to serve more cases.

5.7 Summary and conclusion

Supporting the decision making process is an essential task, because poor decisions have consequences on the implicated stakeholders. This work aimed to ameliorate the decision and policy making processes by introducing visual representations and ontologies in the core of the before mentioned processes. The framework proposed in this dissertation ignites the perceptual abilities of the stakeholders by visualizing the structured LOD in an interactive manner. Both visual analytics and ontologies conduce to the process by making visible characteristics that otherwise would be omitted, by structuring the information to be easier processed by the system. They also facilitate the data flow in the system by aligning the information to each component of the system: the ontology structures the data that is imported to the system, and then the structured data is parsed in the MCDM process, which finally conveys the information to the visual analytics component and to the web interface.

Multiple criteria decision support is a research area that involves complex and multidimensional information. When the final choice must be made by the end users, their abilities and background knowledge must be taken into account in the design process of a decision making system to aid and facilitate informed decisions. MCDM ranking provides adequate transparency in its decision-making processes [281]. We have provided examples of the possible enhancements of this multi-criteria decision aiding procedure with visual analytics and ontologies. The related information is open and inclusive, because of the synergy of these research areas. The introduction of the visual analytics and ontologies in the multidimensional decision support process enhance the process by terms of the time needed to conclude in a decision and the effort put in such a task.

Index of abbreviations

AcademIS	Academic Information System
AHP	Analytic hierarchy process
AIISO	Academic Institution Internal Structure Ontology
ANP	Analytic network process
ARGUS	Achieving Respect for Grades by Using ordinal Scales only
CASRAI	Consortia Advancing Standards in Research Administration Information
CERIF	Common European Research Information Format
CHE	Center for Higher Education
CODE	Commercially Empowered Linked Open Data Ecosystems in Research
CONSENSUS	Confronting social and environmental sustainability with economic pressure
CQ	Competency Questions
CSS	Cascading Style Sheets
CSV	Comma-separated values
DEL	Decision Exploration Lab
DITSCAP	Defense Information Technology Security Certification and Accreditation Process
DIVE	Data Intensive Visualization Engine
DL	Description Logic
DM	Decision Maker
DOGMA	Developing Ontology-Grounded Methods and Applications
DSS	Decision Support System
EA	Evolutionary Algorithms
ELECTRE	ELimination Et Choix Traduisant la REalité
FOAF	Friend-Of-A-Friend
GIS	Geographic Information System
GVA	GeoVisual Analytics
HEEACT	Higher Education Evaluation and Accreditation Council of Taiwan
HEIs	Higher Education Institutions

HERO	Higher Education Reference Ontology
HTML	HyperText Markup Language
ICT	Information and communications technology
IMO	Interactive Multi-objective Optimization
IREMA	Institutional REsearch MAnagement
IRI	Internationalized Resource Identifier
IRIS	Interactive Robustness analysis and parameters' Inference software for multicriteria Sorting problems
JSON	JavaScript Object Notation
KAD	Knowledge-Argument-Decision
LD	Linked Data
LOD	Linked Open Data
LODE-BD	Linked Open Data (LOD)-enabled bibliographical data
MADM	Multiple Attribute Decision Making
MAUT	Multi-Attribute Utility Theory
MAVT	Multi-Attribute Value Theory
MCA	Multi-criteria Analysis
MCDA	Multiple criteria Decision Analysis
MCDM	Multiple criteria Decision Making
MCDSS	Multiple Criteria Decision Support Systems
MIS	Management Information Systems
MOBVR	Multidimensional Ontology Based Visual Ranking
MODM	Multiple Objective Decision Making
MOEAs	Multi-objective Evolutionary Algorithms
MOO	Multi-objective Optimization
MOOViz	Multi-Objective Optimization and Visualization Tool
MS	Management Science
N3	Notation 3
OAF	Ontology-based Argumentation Framework
OMs	Outranking Methods
OR	Operations Research
OURAL	Ontologies pour l'Utilisation de Ressources de formation et d'Annotations sémantiques en Ligne

OWL	Web Ontology Language
PCP	Parallel Coordinates Plots
PDO	Problem Domain Ontology
PROMETHEE	Preference Ranking Organization METHod for Enrichment of Evaluations
RDF	Resource Description Framework
RDFS	Resource Description Framework Schema
RIF	Rule Interchange Format
SDR	Semantic Decision Rules
SKOS	Scientific research and the Simple Knowledge Organization System
SMART	Simple Multi-Attribute Rating Technique
SPARQL	SPARQL Protocol and RDF Query Language
SPEA	Strength Pareto EA
SPQs	Semantic Predefined Queries
SW	Semantic Web
SWRL	Semantic Web Rule Language
THE	Times Higher Education
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
Univ-Bench	University Benchmark
URI	Uniform Resource Identifier
UTA	UTilités Additives
VA	Visual Analytics
VIVO-ISF	VIVO Integrated Semantic Framework
W3C	World Wide Web Consortium
WB	World Bank
WDI	World Development Indicators
WWW	World Wide Web
XML	eXtensible Markup Language
xmlns	XML Namespaces

Appendix

Appendix 1 – Academic ontologies

Ontoural

Learning situation

- Project
- Case study
- Critical analysis
- Problem situation
- Exercise
- Debate
- Cyber quest

Role

- Teacher
- Coordinator
- Learner
- Expert
- Professional

Material

- Document
    - Chart
    - Course content
    - Learning situation text
        - Learner Text
        - Tutor Text
    - Learner production
- Self-assessment system
- Simulation

Actor

- Collective actor
- Teacher's group
    - Educational group

Academic staff

Learners group

Class

Project group

Teachers Learners Group

Individual

Mediation context

Face to face context

Amphitheater

Room

Lab

Company

Distant context

Virtual environment

Tool

Service

Material Environment

Assessment

Collective assessment

Individual assessment

Task

Unitary task

Collective task

Disjoinctive task

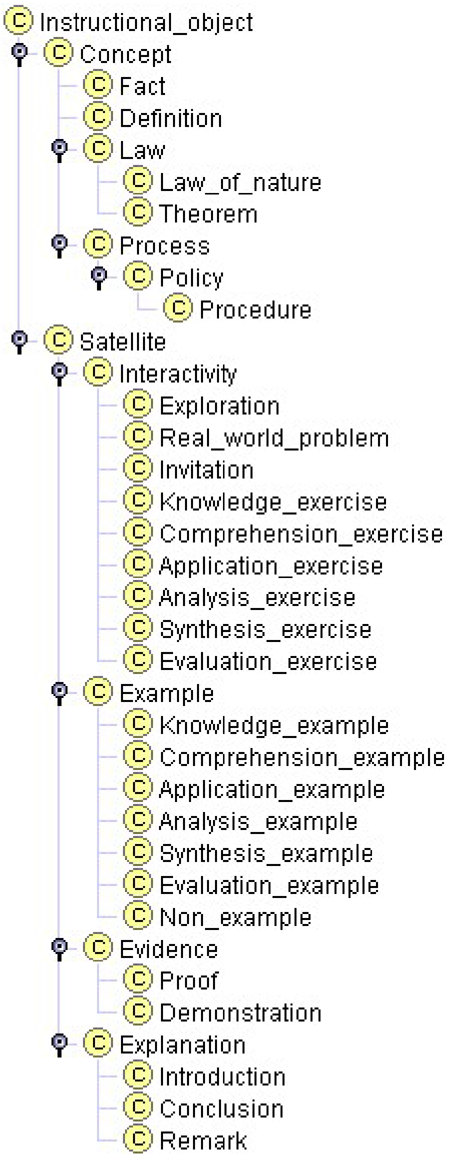
Conjoictive task

Additive task

Compensatory task

Individual task

OIO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Concept
Fact
Definition
Law
Law_of_nature
Theorem
Process
Policy
Procedure
Satellite
Interactivity
Exploration
Real_world_problem
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Analysis_exercise
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Evaluation_exercise
Example
Knowledge_example
Comprehension_example
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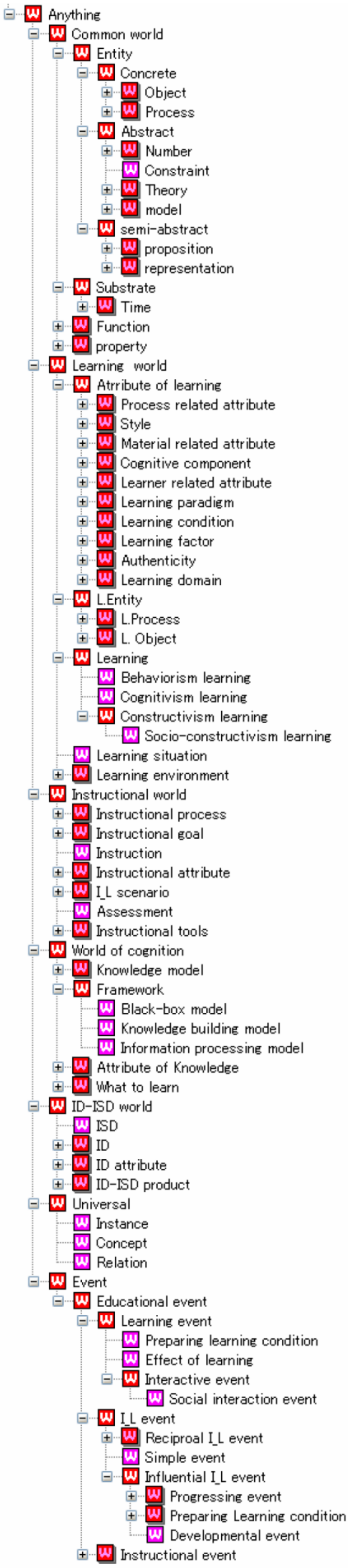
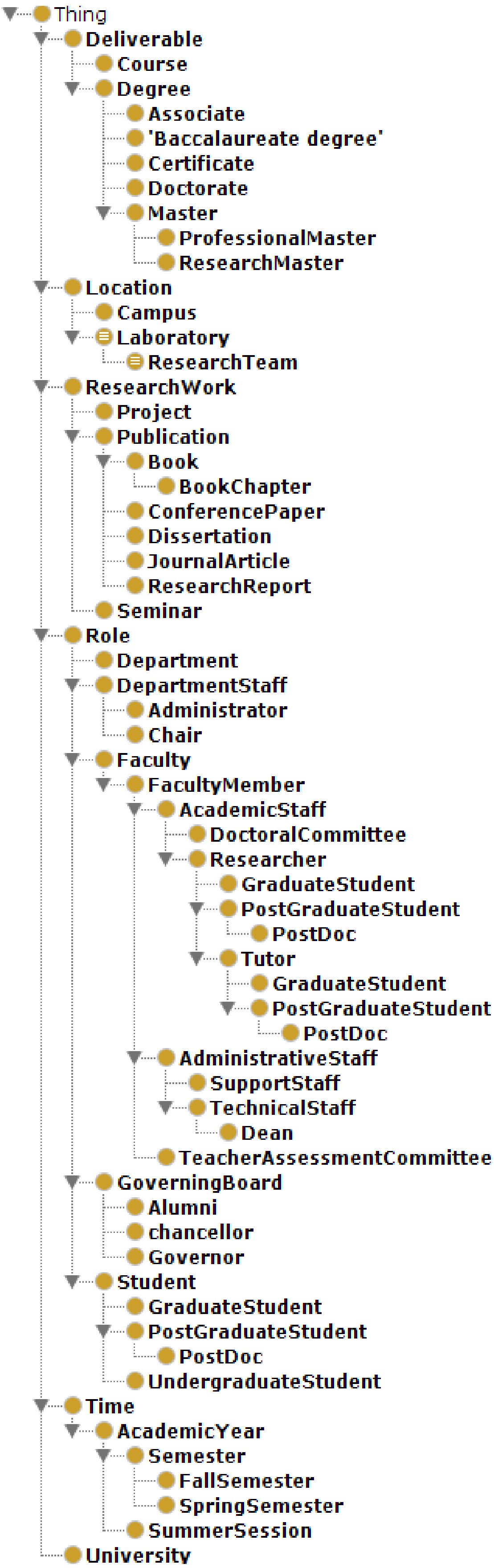
Non_example
Evidence
Proof
Demonstration
Explanation
Introduction
Conclusion
Remark

OMNIBUS


Anything
Common world
Entity
Concrete
Object
Process
Abstract
Number
Constraint
Theory
model
semi-abstract
proposition
representation
Substrate
Time
Function
property
Learning world
Atrribute of learning
Process related attribute
Style
Material related attribute
Cognitive component
Learner related attribute
Learning paradigm
Learning condition
Learning factor
Authenticity
Learning domain
L.Entity
L.Process
L. Object
Learning
Behaviorism learning
Cognitivism learning
Constructivism learning
Socio-constructivism learning
Learning situation
Learning environment
Instructional world
Instructional process
Instructional goal
Instruction
Instructional attribute
I_L scenario
Assessment
Instructional tools
World of cognition
Knowledge model
Framework
Black-box model
Knowledge building model
Information processing model
Attribute of Knowledge
What to learn
ID-ISD world
ISD
ID
ID attribute
ID-ISD product
Universal
Instance
Concept
Relation
Event
Educational event
Learning event
Preparing learning condition
Effect of learning
Interactive event
Social interaction event
I_L event
Reciproal I_L event
Simple event
Influential I_L event
Progressing event
Preparing Learning condition
Developmental event
Instructional event

HERO


Thing
Deliverable
Course
Degree
Associate
'Baccalaureate degree'
Certificate
Doctorate
Master
ProfessionalMaster
ResearchMaster
Location
Campus
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ResearchWork
Project
Publication
Book
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Researcher
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PostDoc
UndergraduateStudent
Time
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Semester
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SpringSemester
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University

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